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FINAL

**Work Plan for a Demonstration of Remediation
by Natural Attenuation for Groundwater at OU 4**



**Hill Air Force Base
Ogden, Utah**

Prepared For:

**Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base
San Antonio, Texas**

and

**Hill Air Force Base
Ogden, Utah**

May, 1997

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FINAL

**WORK PLAN FOR A DEMONSTRATION OF
REMEDATION BY NATURAL ATTENUATION
FOR GROUNDWATER AT OU 4**

at

HILL AIR FORCE BASE, UTAH

August 1996

Prepared for:

**AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
BROOKS AIR FORCE BASE
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CONTENTS

SECTION 1	INTRODUCTION.....	1-1
1.1	SCOPE OF CURRENT WORK PLAN.....	1-3
1.2	BACKGROUND	1-4
1.2.1	Description of the Contaminant Source Area	1-4
1.3	OTHER SITE REMEDIATION ACTIVITY	1-4
SECTION 2	DATA REVIEW & CONCEPTUAL MODEL DEVELOPMENT... 2-1	
2.1	DATA REVIEW	2-1
2.1.1	Physiography, Topography, Surface Hydrology, and Climate	2-1
2.1.2	Overview of Geology and Hydrogeology	2-2
2.1.2.1	Regional Geology and Hydrogeology	2-2
2.1.2.2	OU 4 Geology and Hydrogeology	2-11
2.1.3	Nature and Extent of Contamination at OU 4.....	2-16
2.1.3.1	Soil Contamination	2-16
2.1.3.2	Groundwater Contamination.....	2-17
2.1.3.3	Contaminant Transport and Preferential Pathways.....	2-22
2.1.4	Groundwater Geochemistry	2-25
2.2	DEVELOPMENT OF CONCEPTUAL MODELS	2-30
2.2.1	RNA and Solute Transport Models.....	2-31
2.2.2	Biodegradation of CAHs.....	2-31
2.2.2.1	Electron Acceptor Reactions (Reductive Dehalogenation). 2-32	
2.2.2.2	Electron Donor Reactions	2-34
2.2.2.3	Cometabolism	2-35
2.2.2.4	Behavior of Chlorinated Solvent Plumes.....	2-35
2.2.2.4.1	Type 1 Behavior.....	2-37
2.2.2.4.2	Type 2 Behavior.....	2-37
2.2.2.4.3	Type 3 Behavior.....	2-37
2.2.2.4.4	Mixed Behavior	2-38
2.2.2.4.5	Abiotic Transformations	2-38
2.2.3	Preliminary Conceptual Model	2-39
SECTION 3	COLLECTION OF ADDITIONAL DATA	3-1
3.1	SOIL SAMPLING AND ANALYSIS.....	3-5
3.1.1	Soil Sampling Locations and Analyses.....	3-5
3.1.2	Sample Collection Using the Geoprobe® System.....	3-5
3.1.3	Datum Survey	3-9
3.1.4	Site Restoration.....	3-9
3.1.5	Equipment Decontamination Procedures.....	3-9
3.2	MONITORING POINT INSTALLATION	3-10
3.2.1	Monitoring Point Locations and Completion Intervals	3-10
3.2.2	Monitoring Point Installation Procedures	3-11
3.2.2.1	Pre-Placement Activities.....	3-11

	3.2.2.2 Monitoring Point Materials Decontamination	3-11
	3.2.2.3 Installation and Materials.....	3-11
	3.2.2.3.1 Deep Monitoring Points.....	3-11
	3.2.2.3.2 Shallow Monitoring Points	3-12
	3.2.2.4 Monitoring Point Completion or Abandonment.....	3-14
	3.2.3 Monitoring Point Development and Records	3-14
	3.2.4 Monitoring Point Location and Datum Survey.....	3-16
	3.2.5 Water Level Measurements	3-16
3.3	GROUNDWATER SAMPLING PROCEDURES.....	3-16
	3.3.1 Preparation for Sampling	3-17
	3.3.1.1 Equipment Cleaning.....	3-18
	3.3.1.2 Equipment Calibration	3-18
	3.3.2 Well and Monitoring Point Sampling Procedures	3-18
	3.3.2.1 Preparation of Location.....	3-21
	3.3.2.2 Water Level and Total Depth Measurements	3-21
	3.3.2.3 Monitoring Well/Point Purging	3-21
	3.3.2.4 Sample Extraction.....	3-22
	3.3.2.5 Grab Sampling	3-22
	3.3.3 Groundwater Sampling at Springs.....	3-22
	3.3.4 Onsite Groundwater Parameter Measurement	3-23
	3.3.4.1 Dissolved Oxygen Measurements.....	3-23
	3.3.4.2 pH, Temperature, and Specific Conductance.....	3-23
	3.3.4.3 Oxidation/Reduction Potential.....	3-24
	3.3.4.4 Alkalinity Measurements	3-24
	3.3.4.5 Nitrate- and Nitrite-Nitrogen Measurements	3-24
	3.3.4.6 Sulfate and Sulfide Sulfur Measurements.....	3-25
	3.3.4.7 Total Iron, Ferrous Iron, and Ferric Iron Measurements	3-25
	3.3.4.8 Manganese Measurements	3-25
	3.3.4.9 Carbon Dioxide Measurements.....	3-25
3.4	SAMPLE HANDLING FOR LABORATORY ANALYSIS.....	3-26
	3.4.1 Sample Preservation.....	3-26
	3.4.2 Sample Container and Labels	3-26
	3.4.3 Sample Shipment	3-26
	3.4.4 Chain-of-Custody Control	3-27
	3.4.5 Sampling Records	3-27
	3.4.6 Laboratory Analyses	3-28
3.5	AQUIFER TESTING.....	3-28
	3.5.1 Slug Tests.....	3-28
	3.5.1.1 Definitions.....	3-29
	3.5.1.2 Equipment.....	3-29
	3.5.1.3 General Test Methods	3-30
	3.5.1.4 Falling Head Test.....	3-30
	3.5.1.5 Rising Head Test.....	3-32
	3.5.1.6 Slug Test Data Analysis.....	3-33
	3.5.2 Downhole Flowmeter Testing.....	3-33

3.5.2.1	Experiment Design.....	3-33
3.5.2.2	Procedure	3-33
3.5.3	Spring Discharge Rate Measurement.....	3-34
3.6	MICROCOSM STUDIES.....	3-34
3.6.1	Microcosm Sample Collection.....	3-35
3.6.2	Microcosm Construction and Sampling.....	3-36
SECTION 4 QUALITY ASSURANCE/QUALITY CONTROL		4-1
SECTION 5 DATA ANALYSIS AND REPORT.....		5-1
SECTION 6 REFERENCES.....		6-1

APPENDICES

APPENDIX A	HYDROGEOLOGICAL AND GEOTECHNICAL DATA
APPENDIX B	VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER (1986-1995)
APPENDIX C	TRACE METALS DETECTED IN GROUNDWATER (1986- 1995)
APPENDIX D	DISSOLVED INORGANIC CONSTITUENTS DETECTED IN GROUNDWATER (1986-1995)
APPENDIX E	ANALYTICAL METHODS, DATA USE, AND PACKAGING REQUIREMENTS FOR SOIL AND GROUNDWATER SAMPLES

TABLES

3.1	Analytical Protocol for Groundwater and Soil	3-3
4.1	QA/QC Sampling Program	4-2

FIGURES

1.1	Location Map, Operable Unit 4, Hill AFB	1-5
1.2	Location of Data Collection Sites and Sections in the Area of OU 4	1-6
2.1	Generalized Stratigraphy of the Hill AFB Area	2-3
2.1a	Hill AFB Surface Geology	2-4
2.2	Operable Unit Groundwater Plume Location Map	2-6
2.3	Hydrostratigraphic Cross-Section A-A'	2-7
2.4	Hydrostratigraphic Cross-Section B-B'	2-8
2.5	Lateral Variation in Lithologic Character in the First 35 to 75 Feet BLS Along Section A-A	2-13
2.6	Lateral Variation in Lithologic Character in the First 60 to 80 Feet BLS in the Area of OU 4	2-14
2.7	Altitude of Potentiometric Surface of the Shallow Groundwater and Sunset Aquifers at OU 4	2-15
2.8	Maximum Concentrations of Trichloroethene in Shallow Groundwater in the Area of OU 4	2-18
2.9	Vertical, Lateral, and Temporal Variations of Trichloroethene Concentration in Groundwater Along Section A-A', 1896-1992, in the Area of OU 4	2-19

2.10	Vertical, Lateral, and Temporal Variations of Trichloroethene Concentration in Groundwater Along Section B-B', 1896-1992, in the Area of OU 4	2-20
2.11	Approximate Movement of Trichloroethene Along Section C-C' From Probable Contaminant Source to Discharge Location in the Area of OU 4 ..	2-21
2.12	TCE Concentrations March-September 1994, OU 4	2-23
2.13	Concentration of Dissolved Solids and Area Where the Concentration of Sulfate Exceeds 100 Milligrams per Liter in the Area of OU 4	2-24
2.14	Water Quality Diagrams for Selected Wells and Davis-Weber Canal in the Area of OU 4.....	2-26
2.15	Sulfate, Nitrate, Iron, and Manganese in the Groundwater Along Section A- A', 1992, in the Area of OU 4.....	2-27
2.16	Sulfate, Nitrate, Iron, and Manganese in the Groundwater Along Section B-B', 1992, in the Area of OU 4.....	2-28
2.17	Sulfate, Nitrate, Iron, and Manganese in the Groundwater Along Section C-C', 1992, in the Area of OU 4.....	2-29
2.18	Anaerobic Reductive Dehalogenation	2-33
2.19	Aerobic Degradation	2-36
3.1	Cross-Section of Geoprobe®	3-7
3.2	Geologic Boring Log	3-8
3.3	Monitoring Point Installation Record	3-13
3.4	Monitoring Point Development Record.....	3-15
3.5	Groundwater Sampling Record.....	3-19
3.6	Aquifer Test Data Form	3-31

ACRONYMS AND ABBREVIATIONS

°C	degrees centigrade
°F	degrees Fahrenheit
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
bgl	below ground level
BNAE	base-neutral acid-extractable
BTEX	benzene, toluene, ethylbenzene, xylenes
CA	chloroethane
CAH	chlorinated aliphatic hydrocarbon
CDP	Chemical Disposal Pit
cm/sec	centimeters per second
CPT	cone penetrometer test
CSR	CalScience Research, Inc.
DCA	dichloroethane
DCB	dichlorobenzene
DCE	dichloroethene
DO	dissolved oxygen
ES	Engineering-Science, Inc.
ft/day	feet per day
ft ² /day	square feet per day
ft/ft	feet per foot
ft/min	feet per minute
FTA	Fire Training Area
HARM	Hazardous Assessment Rating Methodology
HDPE	high density polyethylene
ID	inside diameter
IRP	Installation Restoration Program
IWTP	industrial wastewater treatment plant
JMM	James M. Montgomery, Consulting Engineers, Inc.
L/min	liters per minute
LCS	laboratory control sample
LF	Landfill
LMB	laboratory method blank
LNAPL	light non-aqueous phase liquid
LTM	long-term monitoring
MCL	maximum concentration limit
MEK	methyl ethyl ketone
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
msl	mean sea level
mV	millivolt

NPL	National Priority List
NRMRL	National Risk Management Research Laboratory
OD	outside diameter
ORD	Office of Research and Development
ORP	oxidation-reduction potential
OSWER	Office of Solid Waste and Emergency Response
OU	Operable Unit
OVM	Organic Vapor Meter
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PID	photoionization detector
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
Radian	Radian Corporation
RAP	remedial action plan
redox	reduction/oxidation
RI	Remedial Investigation
RNA	remediation by natural attenuation
SAIC	Science Applications International Corporation
SDWA	Safe Drinking Water Act
TCA	trichloroethane
TCE	trichloroethene
TCLP	toxicity characteristic leaching procedure
TD	total depth
TDS	total dissolved solids
TOC	total organic carbon
TPH	total petroleum hydrocarbons
USAF	United States Air Force
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UST	underground storage tank
VC	vinyl chloride
VOC	volatile organic compound
WOST	waste oil storage tank
WP	work plan
WPOP	waste phenol/oil pit

SECTION 1

INTRODUCTION

This work plan (WP) was prepared by Parsons Engineering Science, Inc. (Parsons ES) to define the scope of work and procedures required to evaluate remediation by natural attenuation (RNA) of groundwater contaminated with chlorinated aliphatic hydrocarbons (CAHs) at Operable Unit 4 (OU 4), Hill Air Force Base (AFB), Utah. To this end, this work plan presents a preliminary conceptual model based on available data, and provides suggested protocols to fill the identified data gaps necessary to develop a more thorough conceptual model of groundwater flow and RNA at OU 4. The CAH plume covers an area of about 60 acres of which approximately 45 acres are off-base. Landfills have been identified as the primary source of the groundwater contamination. Trichloroethene (TCE) is the primary CAH contaminant. Leachate from the landfills has migrated into shallow groundwater and has been transported under the influence of steep hydraulic gradients to hillside discharge points.

For the purposes of this WP, RNA is defined as a management strategy that relies on natural attenuation mechanisms to bring about a reduction in the total mass of contaminants dissolved in groundwater, and to control receptor exposure risks associated with this contamination. Natural attenuation is defined by the United States Environmental Protection Agency (USEPA) Offices of Research and Development (ORD) and Solid Waste and Emergency Response (OSWER), as follows:

The biodegradation, dispersion, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem.

As suggested by this definition, there are destructive and non-destructive mechanisms of natural attenuation. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts. During biodegradation, indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the addition of nutrients. Patterns and rates of natural attenuation can vary markedly from site to site depending on governing physical and chemical processes.

RNA provides advantages over other remedial options for the following reasons:

- Contaminants are transformed to innocuous byproducts (e.g., carbon dioxide, ethene, or water), while other remedial options may result in contaminant transformation from one phase to another, or contaminant transport to another location within the environment;
- Current engineered remedial options (e.g., pump-and-treat technologies) may be energy-intensive and generally are not as effective as RNA in reducing residual contamination;
- Engineered remedial technologies may pose a greater risk to potential receptors than RNA (i.e., the use of engineered remedial technologies may disturb the existing contaminant equilibrium, increasing contaminant mobility in the subsurface, resulting in the transfer of contaminants to non-contaminated media, etc.);
- The RNA process is non-intrusive, and allows continuing use of infrastructure during remediation; and
- RNA is less costly than most conventional remedial technologies.

Natural attenuation has the following potential limitations:

- The success of natural attenuation is controlled by natural conditions including local hydrogeologic conditions [e.g., changes in groundwater gradients/velocity, potential of hydrogen (pH), electron acceptor concentrations, electron donor availability, potential future contaminant releases, oxidation/reduction potential, etc.] and these conditions may be influenced by human activities;
- Aquifer heterogeneity may complicate site characterization, and evaluation, and may influence the nature of RNA processes at a given site;
- Microorganisms capable of biodegradation must be present;
- Restoration of contaminated groundwater using RNA is dependent on the nature of contamination, aquifer characteristics, environmental conditions, etc., and may require extended periods of time;
- Some intermediate products of biodegradation (e.g., vinyl chloride) are more toxic than the original contaminant; and
- Alternate present and potential future sources of contamination may contribute to the total mass of contamination present at a site, and may affect the time required to restore contaminated groundwater.

1.1 SCOPE OF CURRENT WORK PLAN

The purpose of this work plan is to outline the protocols necessary to demonstrate that RNA with long-term monitoring (LTM) is a viable method of remediating contaminated groundwater at OU 4. The main objective of the demonstration is to provide solid evidence of the RNA of dissolved CAHs, so that this information can be used to develop an effective groundwater remediation strategy in which RNA is a major part of the overall site remediation plans for OU 4. Although the hydrogeologic and analytical data collection methods described in this work plan may be adequate to evaluate other remedial options, these data are intended to evaluate contaminant transport and natural attenuation, and may not provide sufficient data to evaluate other remedial options adequately. The results are expected to support RNA with LTM as a method of remediation of CAH-contaminated groundwater at OU 4.

This WP was developed through discussions that included representatives from Hill AFB, the State of Utah Department of Environmental Quality (CERCLA and RCRA divisions), the USEPA - Region VIII, the Air Force Center for Environmental Excellence (AFCEE), the USEPA National Risk Management Research Laboratory (NRMRL), Parsons ES, and Hill AFBs' prime consultants. A workshop on natural attenuation of chlorinated solvents was conducted on 3 April 1996 and included representatives from these groups. In addition, an expert from Beak Consultants and Utah State University participated. The purpose of this workshop was to evaluate the site-specific approach for RNA at various sites, including OU 4, based on a review of available site characterization data. The final portion of the discussion was directed toward establishing a conceptual model of each OU and recommendations for possible action, including suggested data collection that might be used to fill "data gaps" associated with a particular OU.

This WP was prepared for AFCEE and Hill AFB. It is not intended to fulfill the requirements of a contamination assessment report, a remedial action plan (RAP), or any other document specified in federal or state regulations. The information contained herein is provided for the use of Hill AFB, and state and federal regulatory agencies. This information is intended to be used for future decision-making at OU 4.

This WP consists of six sections, including this introduction. Section 2 presents a review of available, previously reported data for OU 4 and the surrounding area, where it is pertinent to the evaluation of RNA, and the development of the preliminary conceptual model for OU 4. Section 3 describes the proposed sampling strategy and procedures to be used for the collection of additional data necessary to fully evaluate RNA and refine the conceptual model for OU 4. Section 4 presents proposed quality assurance/quality control (QA/QC) measures. Section 5 describes data analysis and remedial option evaluation. Section 6 contains references used in preparing this document. There are five appendices included with this WP. Appendix A contains hydrogeological data and

geotechnical data. Appendix B, Appendix C, and Appendix D contain selected analytical data from previous work performed at OU 4. Appendix E contains a listing of analytical methods and containers, data use, and sampling and laboratory requirements for soil and water-matrix analytical samples.

1.2 BACKGROUND

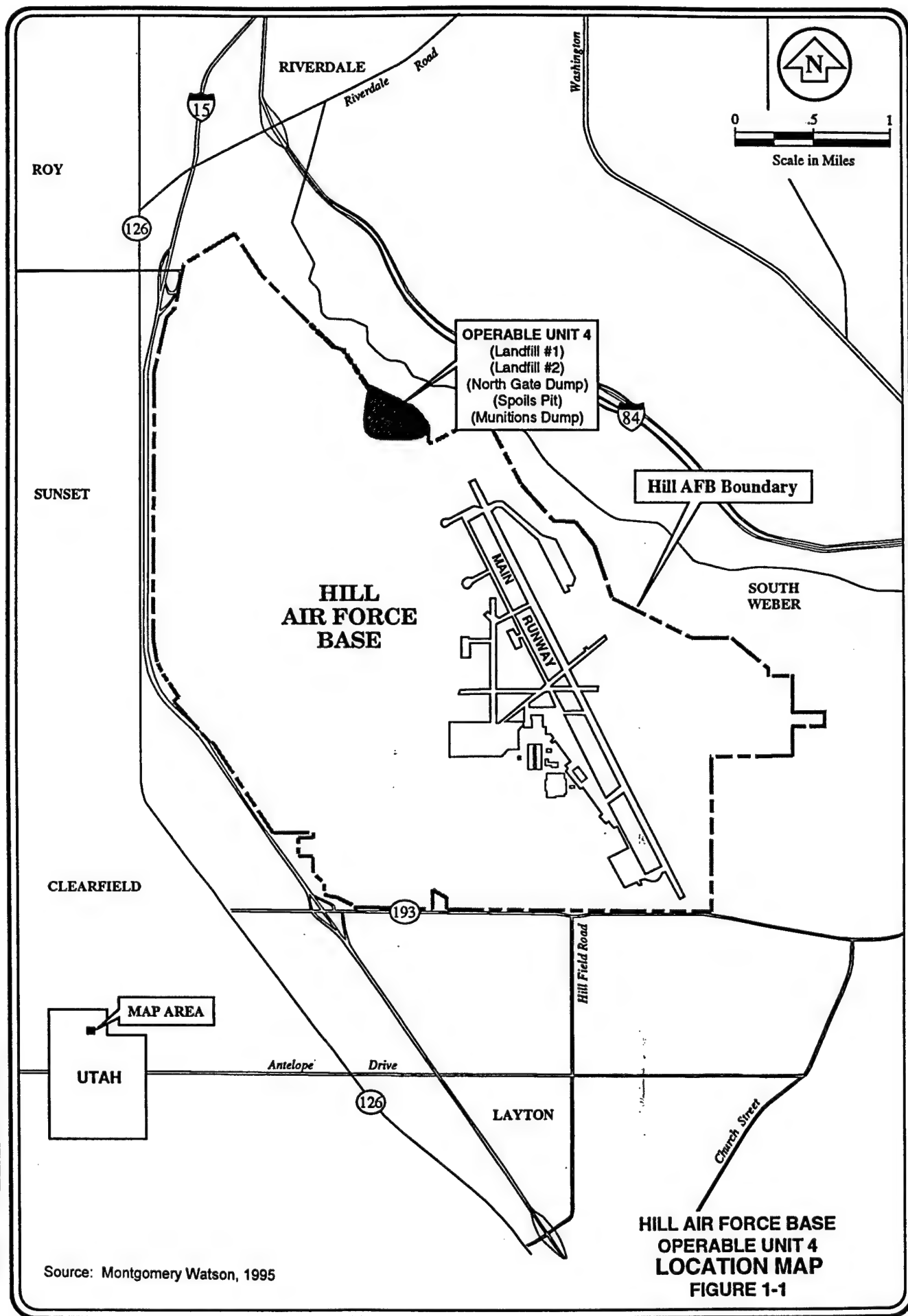
In July 1988, the U.S. Geological Survey (USGS) began a Remedial Investigation (RI) at OU 4. The RI work was completed in 1992. Since 1992, Montgomery Watson, Inc. has performed remedial design work at the OU, and monitoring groundwater for analytical parameters has continued. The location of OU 4 is shown in Figure 1.1. The OU consists of the five sites shown in Figure 1.2.

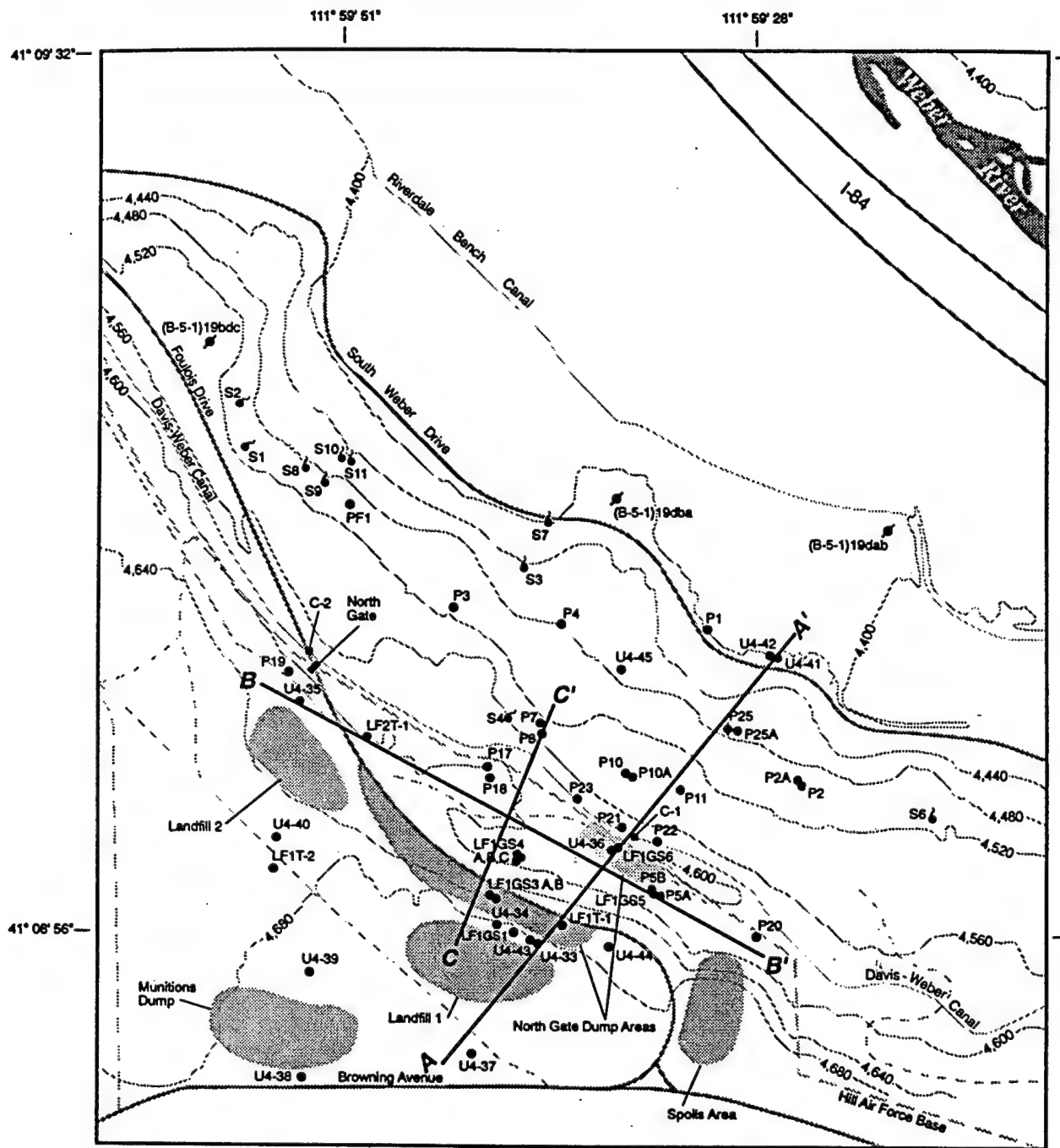
1.2.1 Description of the Contaminant Source Area

The RI activities at OU 4 delineated a TCE plume that extends beyond the Base boundary. Through continued investigation at OU 4, the western half of Landfill 1 was determined to be the primary source of TCE groundwater contamination (Montgomery Watson, 1994). Landfill 1 covers about 5 acres and is located on a relatively flat terrace. Base personnel recall that the landfill began operation in 1955. Recent trenching work at the landfill (1995) indicated that the total depth is approximately 35 feet below land surface (bls); perched groundwater was not observed (OU 4 project manager, personal communication). Available records indicate that few, if any, chemicals were disposed in the landfill. However, Landfill 1 may have received waste from the Ogden Arsenal that included waste solvents and oils (USGS, 1992). Recent intrusive data indicates an additional potential source of contamination by Landfill 2, which is located about 1,000 feet northwest of Landfill 1 (OU 4 project manager, personal communication).

1.3 OTHER SITE REMEDIATION ACTIVITY

Some remedial design work subsequent to the RI has been accomplished at the site; pilot scale horizontal drains have been placed to passively collect contaminated groundwater. The collected water is routed to an off-base air stripping treatment system. After on-site treatment the water is discharged via a temporary pipeline to the sanitary sewer. A larger-scale groundwater treatment facility is currently under construction and Landfill 1 has been capped (OU 4 project manager, personal communication).





- EXPLANATION**
- A—A'** SECTION LINE
- HILL AIR FORCE BASE BOUNDARY
- IMPROVED DIRT ROAD
- SECONDARY DIRT ROAD
- P17
(B-5-1)19dba
S4
- MONITORING WELL AND NUMBER
- PRIVATE OR PUBLIC WELL AND NUMBER
- SEEP AND NUMBER
- P25
- TEST HOLE AND NUMBER
- C-2
- CANAL SAMPLING SITE AND NUMBER

0 500 1,000 FEET
0 100 200 300 METERS
CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Source: USGS, 1993

Figure 1.2 --Location of data-collection sites and sections in the area of Operable Unit 4.

SECTION 2

DATA REVIEW AND CONCEPTUAL MODEL DEVELOPMENT

Existing site-specific data were reviewed to develop a preliminary conceptual model of RNA for groundwater at OU 4. Section 2.1 presents a synopsis of available site characterization data. Section 2.2 discusses the general development of conceptual models, governing principles of CAH biodegradation, behavior of CAH plumes, and lastly, presents the preliminary conceptual model of groundwater flow and RNA at OU 4. This conceptual model guides the development of data requirements needed to more thoroughly evaluate RNA and support the modeling efforts. Proposed sampling locations and the analytical data requirements and sampling protocols are discussed in Section 3.

2.1 DATA REVIEW

The following sections are based on review of data from the following sources:

- USGS, 1992
- USGS, 1993
- Montgomery Watson, 1994, and;
- Montgomery Watson, 1995.

2.1.1 Physiography, Topography, Surface Hydrology, and Climate

Hill AFB is located in northern Utah, approximately 25 miles north of Salt Lake City and 5 miles south of Ogden. The Base contains 6,666 acres in Davis and Weber Counties. The western boundary of the Base is near Interstate 15, and the southern boundary is near State Route 193. The northern and northeastern perimeters of the Base are bounded by the Davis-Weber Canal, a privately-owned irrigation canal. The Wasatch Mountain Range is about 4 miles to the east, and the Great Salt Lake is about 6 miles to the west. The Base is located within the Bonneville Basin subsection of the Great Basin section of the Basin and Range physiographic province.

Hill AFB is located on a plateau which rises approximately 300 feet above the Weber River Valley on the east and approximately 50 to 100 feet above the towns of Sunset and Clinton on the west. Except for areas dissected by erosion, most of HAFB is relatively level, ranging in altitude between approximately 4,550 and 4,800-feet above mean sea level (msl) with higher areas near 4,900-feet in the far eastern portion of the Base near the golf course area. Landfill 1, the identified contaminant source area at OU 4, is situated at the margin of the terrace and hillside at an approximate ground surface elevation of 4,690-feet above msl. The surface topography slopes abruptly and steeply to the northeast of the landfill until leveling at approximately 4,400-feet above msl on the floodplain of the Weber River. Springs or seeps discharge at locations along the hillside with a most occurring at approximately 4,440 feet above msl.

The climate of Hill AFB is semi-arid. Mean annual precipitation is just over 18 inches, and annual evaporation is approximately 45 inches (Feth *et al.*, 1966). At Ogden, just north of Hill AFB, the average temperature is 50.5 degrees Fahrenheit (°F); mean monthly temperatures range from 25°F in January to 75°F in July. Winds average about 5 knots and are generally out of the south and east-southeast, although winds from the north and northwest are common.

2.1.2 Overview of Geology and Hydrogeology

2.1.2.1 Regional Geology and Hydrogeology

The geologic formations exposed at the surface in the vicinity of Hill AFB vary from Precambrian-age crystalline bedrock at the western margin of the Wasatch Mountain Range to Pleistocene unconsolidated deposits forming benches, plateaus, and lowlands west of the Wasatch Front (Figures 2.1 and 2.1a). Hill AFB is situated on a plateau that is an erosional remnant of a fan-delta complex formed when sediments were transported from the Wasatch front into Pleistocene Lake Bonneville. Primarily, coarse-grained fan-delta deposits of the most recent Provo stage of Lake Bonneville are exposed within the boundaries of the Base. The fan-delta has been dissected along the northeastern perimeter of the Base by the Weber River, creating a steep terrace. Older Alpine stage sediments of Lake Bonneville generally underlie the Provo deposits, and the silts, sands, and clays of a lower Alpine unit (Qac) are exposed on the steep hillsides northeast of the Base. Although older than the Provo stage sediments, some of the upper Alpine stage units were deposited at higher altitudes than Provo stage sediments because the lake level was higher during Alpine time. These upper coarse-grained Alpine units (Qag and Qas) crop out at the far eastern portion of the Base and form remnant hilltops.

Symbol	System	Series	Formation and Lithology	Thickness in Feet		
Qa Qg Qs Qc	Quaternary	Recent	Alluvium: Permeable river sand and gravel; includes mudflow deposits near mountains which are impermeable locally. Gravel: Permeable floodplain sand and gravel. Sand: Permeable fine sands underlying lowlands. Clay: Impermeable plastic to non-plastic clay overlying artesian aquifer.	200 10-20 35+		
UNCONFORMITY						
Qpg Qpgs Qps				Pleistocene	(Lake Bonneville Group): Provo Formation: gravel, permeable; gravel and sand, permeable; sand, permeable	5-20 10-50 10-20
Qba					Bonneville and Alpine Formation: sand and gravel over bedrock, very permeable	5-50
Qag Qas Qac					Alpine Formation: gravel, permeable; sand, permeable; clay silt, fine sand, usually impermeable;	<25 100 200
Q			Unconsolidated basin-fill deposits	>1000		
UNCONFORMITY						
Cl	Cambrian	Middle to Late (?)	Limestone: Silty with interbedded shale and dolomite. Permeable.	1375(±)		
Cr		Lower to Middle (?)	Tintic Quartzite: massive, cross-bedded, pebbly. Permeable where fractured.	500-700		
ANGULAR UNCONFORMITY						
Pcf		Precambrian	Farmington Canyon Complex: metasedimentary and metavolcanic rocks. Permeable where jointed or fractured.	10,000		

SOURCE: Modified from Feth et al. (1966)

FIGURE 2.1

GENERALIZED STRATIGRAPHY OF THE HILL AFB AREA

Hill Air Force Base, Utah

**PARSONS
ENGINEERING SCIENCE, INC.**

Source: Radian, 1995.

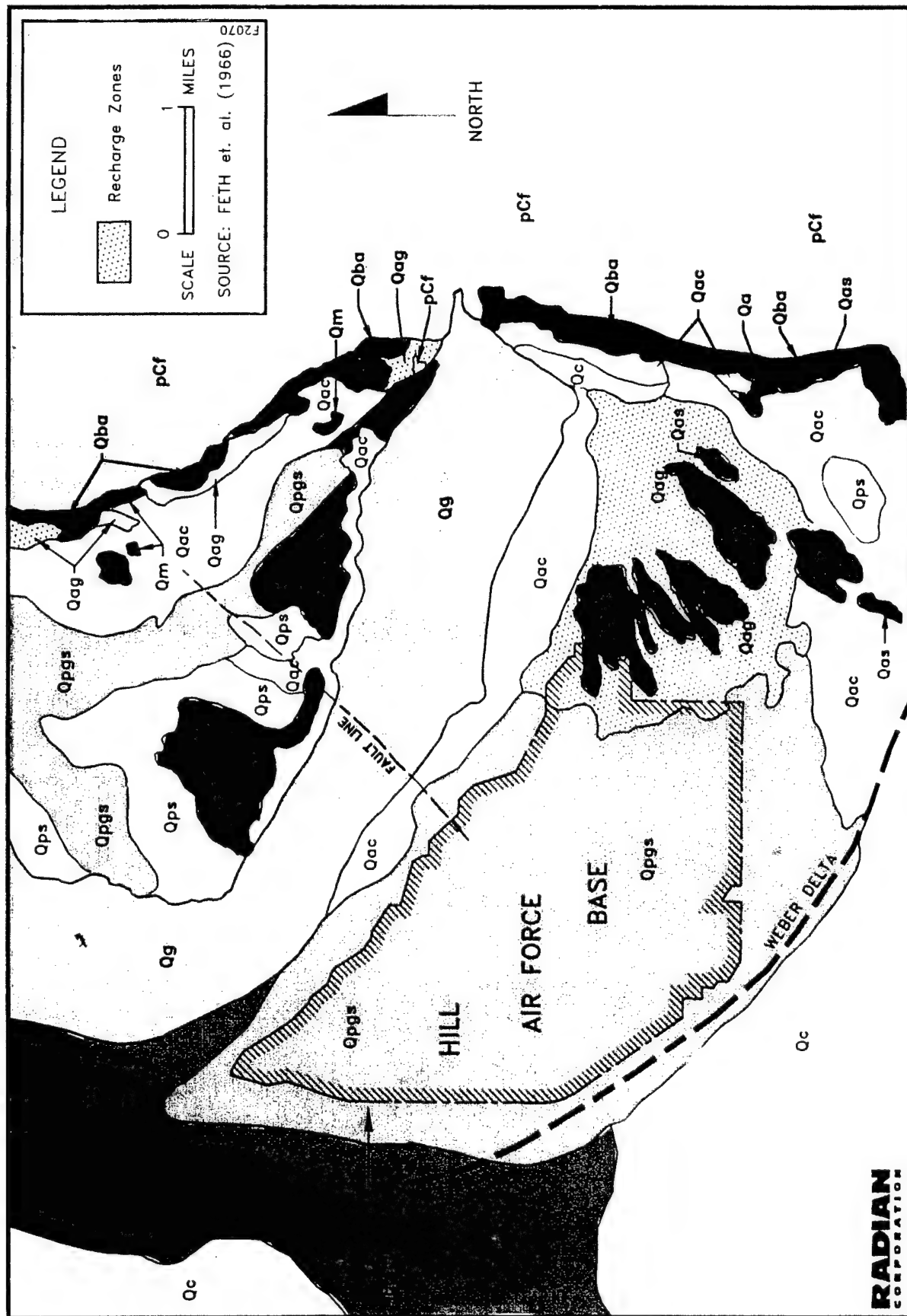
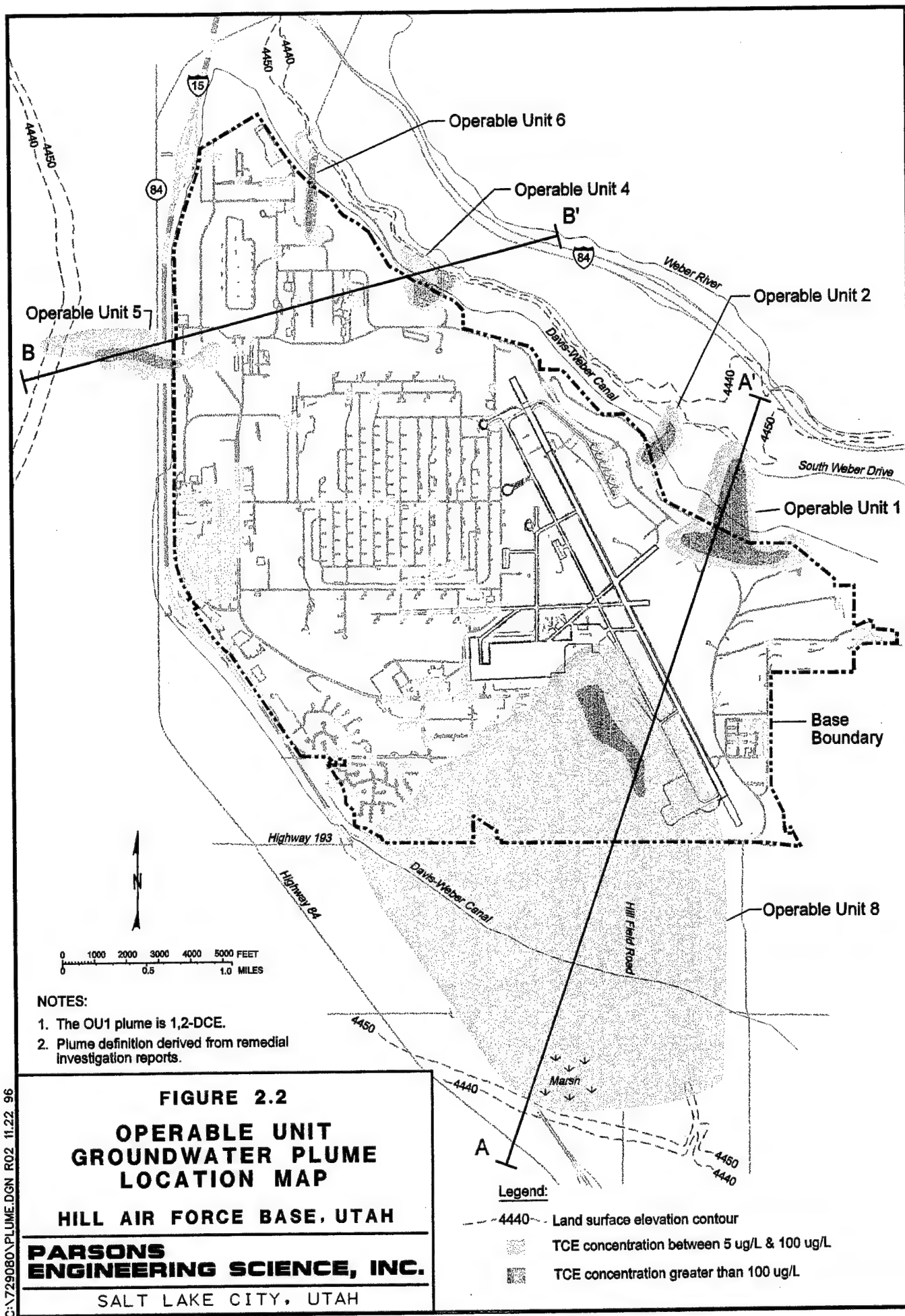


Figure 2.1a Hill AFB Surface Geology (See Figure 2.1 for Description of Map Symbols)

Perched, shallow, water-bearing zones that collectively form a shallow unconfined aquifer system are present in the unconsolidated Provo and Alpine stage Lake Bonneville deposits. Groundwater flow in the shallow groundwater system is to the northeast in the OU 4 area. Elsewhere on the Base, groundwater flow in the shallow groundwater system varies, and the flow direction and magnitude may be locally controlled by topography or subsurface features.

In addition to the formations exposed at the surface, 2,000 to 3,000 feet of pre-Lake Bonneville sediments are present in a north- to south-trending graben underlying the area of Hill AFB (Feth *et al.*, 1966). This basin fill consists of thick sequences of interbedded coarse alluvium and lacustrine clays. The coarse alluvial units are successively older (and deeper) lobes and layers of the fan-delta complex, and they function as artesian aquifers. Two artesian aquifers supply water to Hill AFB and the surrounding communities: the low-transmissivity Sunset Aquifer and the deeper, highly transmissive Delta Aquifer. The general pattern of groundwater flow in the deeper aquifers is east to west, from the recharge areas toward the Great Salt Lake. The potentiometric surfaces in the deep aquifers beneath the Base are relatively flat. However, because of high pumpage, local perturbations of the potentiometric surfaces are evident, and the potentiometric surfaces have been lowered substantially. Cross-sections showing the relationship of the hydrostratigraphic units beneath the base and the potentiometric surfaces of the aquifers have been developed by Parsons ES. The lines of cross-section are shown in Figure 2.2 and cross-sections in Figures 2.3 and 2.4. The hydrostratigraphic cross-sections have been constructed using data obtained from published technical reports and Hill AFB RI results, and drillers' logs of deep production wells.

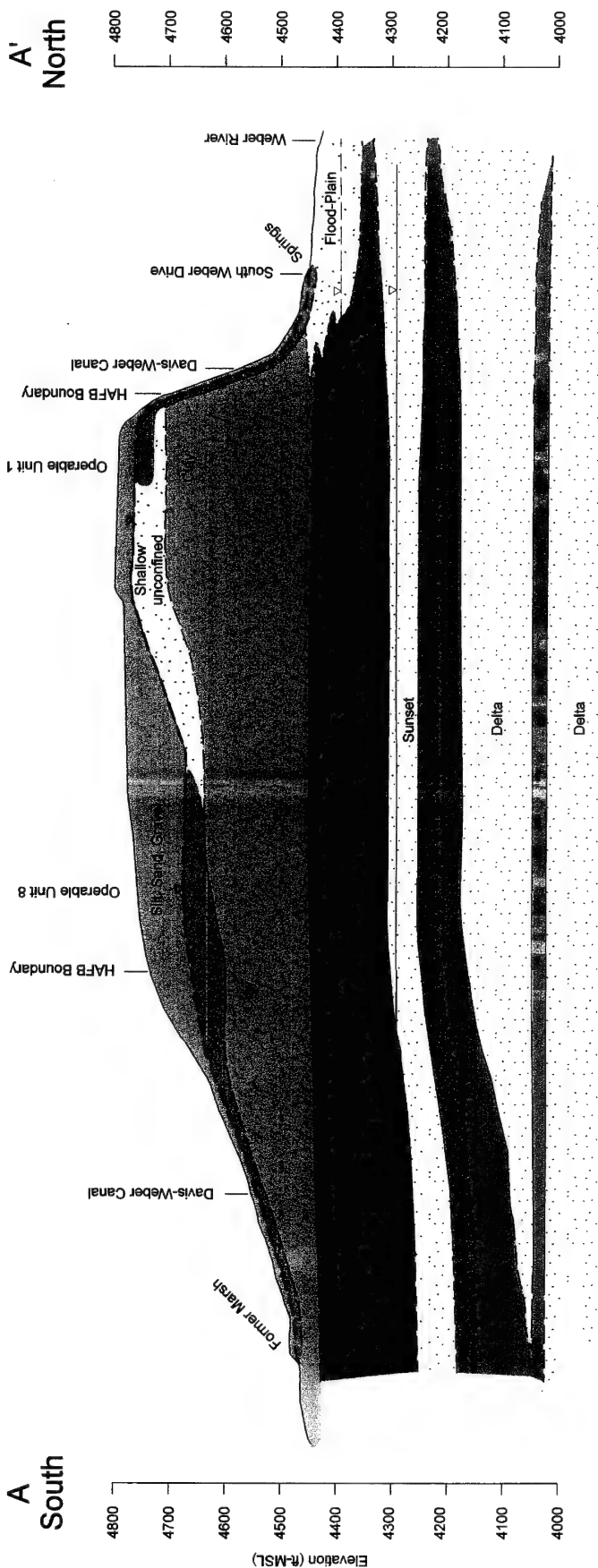
With respect to the regional groundwater flow net, vertical components of flow are downward in recharge areas near the mountain front and upward in discharge areas to the west of the Base near the Great Salt Lake. This general pattern of recharge and discharge may be affected locally by groundwater pumping, but should be relatively unaffected at the regional scale. Based on the potentiometric surfaces of the aquifers beneath the Base, downward components of flow from the shallow unconfined aquifer to the deeper Sunset and Delta aquifers are inferred. However, the downward movement of groundwater through the clay layers and confining units between the aquifers depends on the degree of hydraulic connection among the aquifers, which in turn depends on the thickness and hydraulic properties of the clay layers separating the aquifers. Drillers' logs indicate that the confining units in the area of the Base are primarily tight blue-gray clay. The extensive clays separating the aquifers appear to limit the hydraulic connection among the aquifers, and thus, the amount of recharge and vertical leakage. The deep aquifer system



G:\729080\PLUME.DGN R02 11.22.96

A
South

A'
North



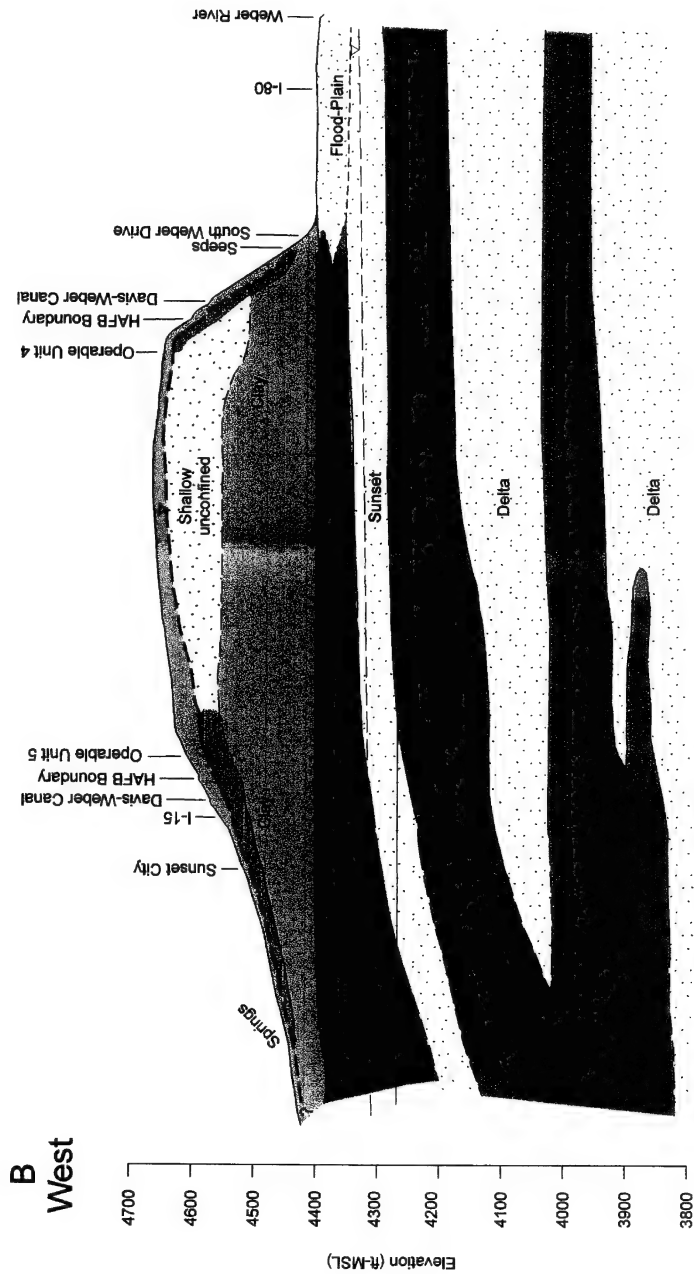
Legend:

- | | | | |
|--|---|--|--|
| | Aquifers (Shallow Unconfined, Flood-plain, Sunset, Delta) | | Shallow Unconfined Aquifer static water level |
| | Groundwater Contaminant Plumes | | Sunset Aquifer potentiometric surface (JMM, 1989) |
| | Lake Bonneville Group (Provo and Alpine Stage) | | Delta Aquifer potentiometric surface - 1985 (Clark and others, 1990) |
| | Confining Units (primarily clay) | | Contact (dashed where inferred) |

0 2000
Horizontal Scale in Feet
Vertical Exaggeration = 10x

FIGURE 2.3
HYDROSTRATIGRAPHIC
CROSS-SECTION A-A'
HILL AIR FORCE BASE, UTAH
PARSONS
ENGINEERING SCIENCE, INC.
SALT LAKE CITY, UTAH

B
West



Legend:

- Aquifers (Shallow Unconfined, Flood-plain, Sunset, Delta)
- Groundwater Contaminant Plumes
- Lake Bonneville Group (Provo and Alpine Stage)
- Confining Units (primarily clay)

- Shallow Unconfined Aquifer static water level
- Sunset Aquifer potentiometric surface (JMM, 1989)
- Delta Aquifer potentiometric surface - 1985 (Clark and others, 1990)
- Contact (dashed where inferred)

Note: Upward hydraulic gradients are present in the Flood-plain Aquifer at OU4 (USGS, 1992)

0 2000
Horizontal Scale in Feet
Vertical Exaggeration = 10x

FIGURE 2.4

HYDROSTRATIGRAPHIC CROSS-SECTION B-B'

HILL AIR FORCE BASE, UTAH

PARSONS ENGINEERING SCIENCE, INC.

SALT LAKE CITY, UTAH

becomes unconfined and less differentiated near the mountain front and the mouth of Weber Canyon. This eastward unconfined extension of the deep aquifer system is the main source of recharge to the deep aquifers. Recharge to the deeper aquifers primarily occurs near the mountain front by direct infiltration into the more permeable Lake Bonneville deposits and by seepage losses from the Weber River. The Sunset and Delta aquifers are better differentiated near OU 4, and the Weber River drainage is underlain by a thicker sequence of clay [see cross-section B-B' (Figure 2.4)]. Therefore, the river does not appear to be a primary source of groundwater influx to the deeper aquifers in the area downgradient from OU 4. Conversely, seepage gains in the river indicate upward leakage from the Sunset Aquifer (USGS, 1992).

High-yield production wells at Hill AFB are screened in one or both coarse-grained water-bearing units of the Delta Aquifer starting at about the 4,200 feet elevation. Logs for city wells to the west and south of Hill AFB indicate that the upper water-bearing unit or lobe of the Delta Aquifer fan complex thins and eventually terminates in these directions. Therefore, this upper lobe is unique to the Hill AFB area. The lower water-bearing unit of the Delta Aquifer is tapped elsewhere outside of the Base. The shallower, lower yield Sunset Aquifer is more differentiated from the Delta Aquifer in the areas west and southwest of the Base and is used for water supply in these areas, though less frequently than the Delta Aquifer.

The areal extent and morphology (derived from the RIs) of the dissolved CAH groundwater plumes at OUs 1, 2, 4, 5, 6, and 8 are in Figure 2.2. The relationships between the geology, topography, hydrostratigraphic units, and selected dissolved CAH plumes beneath Hill AFB are shown on hydrostratigraphic cross-sections A-A' and B-B' (Figures 2.3 and 2.4). As shown in the figures, the plume morphologies and extents are geologically, topographically, and hydrologically controlled, and they all terminate at approximately the same elevation (4,440 to 4,450 feet msl). In the upper part of the fan-delta, the interaction of Lake Bonneville and the delta resulted in a complex system of interfingering lenticular strata where the more coarse-grained units likely act as preferential pathways for contaminant transport. For instance, the groundwater plume at OU 6 is constrained to a long, narrow trough of coarser sediment bounded on all sides by less permeable fine-grained sediments (Figure 2.2). Conversely, the plume at OU 5 is less constrained laterally and is thus wider. All plumes are constrained vertically with depth by the progressively more fine-grained units within the Lake Bonneville Group deposits, with the base of the shallow groundwater system (shallow unconfined aquifer) defined by an irregular contact surface with low-permeability clay (Figures 2.3 and 2.4).

As noted, relatively coarse-grained units may control plume migration in areas with complex and variable stratigraphy. Contaminants likely flow through zones with higher hydraulic conductivities relative to surrounding sediments. Given that the shallow groundwater system beneath Hill AFB consists of highly heterogeneous alluvial sediments deposited in a fan-delta complex, the potential for preferential and rapid migration in coarse-grained units must be considered when evaluating groundwater contaminant migration. For example, at OU 5, groundwater velocity measurements have been collected using a borehole flowmeter (Wheeler, 1996). These data suggest that within a single well, velocities may vary by a factor as great as 10, and that across the site, velocities may differ by a factor of nearly 70 (i.e., nearly two orders of magnitude). This has also been observed at UST Site 870 at Hill AFB (JMM, 1993; Parsons ES, 1995). At that site, slug and pumping tests were conducted in wells screened across different stratigraphic intervals (e.g., some fine grained and some coarse). Results of these tests varied over two orders of magnitude, suggesting that for equivalent gradients and porosities, groundwater velocities at Site 870 could vary by two orders of magnitude. In general, at Site 870, wells with higher measured hydraulic conductivities were screened mostly across sandy intervals, while wells with lower measured conductivities were screened mostly across finer-grained intervals (containing more silt and clay). Due to this heterogeneity, use of an average hydraulic conductivity for transport modeling may not be appropriate.

Contaminants at the OUs have migrated vertically through the coarse, near-surface sediments to the shallow perched water table and have then migrated laterally off-base. The plumes terminate in the vicinity of springs, seeps, or marshy areas. Discharge also occurs at other upslope spring/seep locations at most of the OUs. The spring/seep line of discharge at the downgradient leading edges of the plumes may result from several factors such as structural contacts with clay units, topographic low spots, and upward hydraulic gradients in the lowland areas. Upward hydraulic gradients were confirmed in the Weber River flood-plain silts, sands, and gravels at the downgradient reaches of the OU 4 plume (USGS, 1992), as shown on Figure 2.4. Upward hydraulic gradients in shallow groundwater also may be present at the other OUs, and this as well as other factors (i.e., discharge, evapotranspiration, dilution, dispersion, biodegradation, etc.) appear to be controlling the downgradient extent of the plumes, and may be the reason that the plumes all terminate at approximately the same elevation (see Figure 2.2).

Natural attenuation mechanisms appear to have stabilized the leading edge of the plumes at their current location and elevation. This conclusion is supported by chemical data obtained from the off-base downgradient springs and seeps. Since 1986, many of the

springs and seeps at the downgradient edges of the plumes have been sampled and analyzed for CAHs, with no apparent increasing trend. For example, the spring below Petersons Pond at OU 2 contained TCE at a concentration of 44 micrograms per liter (ug/L) when first sampled in 1986. A maximum TCE concentration of 373 ug/L was detected in May 1987, and concentrations of TCE have diminished since 1987. Seasonal variability may be more significant than long-term trends because concentrations of CAHs in this spring and downgradient springs at the other OUs are generally higher in the late spring and summer months. At OU 8, off-base downgradient field drains have contained CAHs since they were first sampled in the 1980s. During the period from 1986 to 1994, concentrations of TCE ranging from 16 ug/L to 89 ug/L, with no apparent increase, have been detected in a field drain behind the Jay Harris residence, which is located south of the Davis-Weber Canal. Approximately 1,500 feet further downgradient, TCE was detected at concentrations ranging from 11 ug/L to 21 ug/L in water collected from a manhole at the Reed Robins residence. These analytical data are for 1987 only. This location corresponds to the furthest downgradient detection of CAHs at OU 8. A marshy area is located just south of this sampling location and appears to be a point of shallow groundwater discharge (Figure 2.3). However, most of this area recently has been developed, potentially modifying the hydrologic regime. At OU 5, relatively low concentrations of TCE were detected in two shallow domestic wells near 700 West in Sunset as early as 1987. Fred Chicado's well contained TCE at a concentration of 3.4 ug/L in 1987. TCE concentrations ranging from 6.6 ug/L to 7.5 ug/L were detected in Omer's well between 1989 and 1990. Martin Spring has contained concentrations of TCE ranging from 4.4 ug/L to 5.8 ug/L between 1989 and 1990, and a maximum 1,2-DCE concentration of 8.9 ug/L also was detected. The presence of relatively stable concentrations of CAHs in spring water, field drains, and shallow groundwater water far downgradient of the source areas, as early as 1986, implies that the plumes are stable and are no longer increasing in size.

2.1.2.2 OU 4 Geology and Hydrogeology

The hydrogeologic features of the shallow groundwater system in the vicinity of OU 4, and shallow subsurface stratigraphy, have been characterized from the subsurface investigations previously cited. Work performed during the RI (1988-1992) consisted of various geophysical surveys, soil gas surveys, conventional auger drilling and monitoring well installation, and aquifer testing of 25 of the monitoring wells. Lithologies were determined through geophysical methods and borehole logging. A description of subsurface features in the vicinity of OU 4 follows.

The shallow subsurface features at OU 4 are consistent with the regional setting of the Lake Bonneville Provo and Alpine stage deposits. Hydrogeological cross-sections A-A' and B-B' are provided in Figures 2.5 and 2.6 (a hydrogeological cross-section C-C' is not provided in the source text). Lines of section are shown in Figure 1.2. The deposits consist mainly of fine-grained sediments, which include silt and clay, with lesser amounts of silt and fine sand. Distinct layers of coarser material are present. The lithology varies laterally and with depth, although not substantially in the first 60 feet. The sediments of the shallow groundwater system are about 200-feet thick beneath the landfills and become more fine grained with depth. Most groundwater movement near the landfills occurs in interfingered layers of sands and silts in the upper 30-to 60-feet of the sediments. The near-surface sediment along the hillsides, which includes sandy and silty material, is less than 20-feet thick, and some slumping of the hillside sediments has occurred (USGS, 1992). As shown in the cross-sections, groundwater flow is topographically controlled and is primarily constrained to the near surface. Most of the shallow groundwater is thought to discharge in seeps along steep escarpments located at the Base of the hillside but above the valley floor. Consequently, the hydraulic connection between the shallow groundwater system and the Weber River flood plain deposits in the lowland appears to be limited.

Groundwater flow is northeast and downslope toward the valley, and the groundwater depth is shallow along the hillsides. The altitude of groundwater in the shallow groundwater system in July, 1992, is illustrated in Figure 2.7. The hydraulic gradient immediately downgradient of the Base boundary was approximately 0.15 ft/ft on this date. In 1992, some flattening of the hydraulic gradient occurred near the Base boundary due to leakage from the Davis-Weber Canal (USGS, 1992). Cracks in the canal have since been repaired, and the canal no longer leaks.

The hydraulic conductivity of sediments in the shallow groundwater system was calculated from slug tests at the monitoring wells employing the Bouwer and Rice Method (1976). Hydraulic conductivity values ranged from a low of 0.001 ft/day to a high of 10 ft/day, with a median value of 1 ft/day for 13 wells whose screened intervals started at 30 feet or less bls (Table A.1, Appendix A). The median value for 12 wells screened below 30 feet bls was between 0.01 and 0.1 ft/day; the high of 1 ft/day. The USGS (1992) suggests that these values may indicate a trend of decreasing hydraulic conductivity with depth. Three constant discharge pumping tests yielded somewhat higher hydraulic conductivity values ranging from 1.2 ft/day to 2.6 ft/day. Because

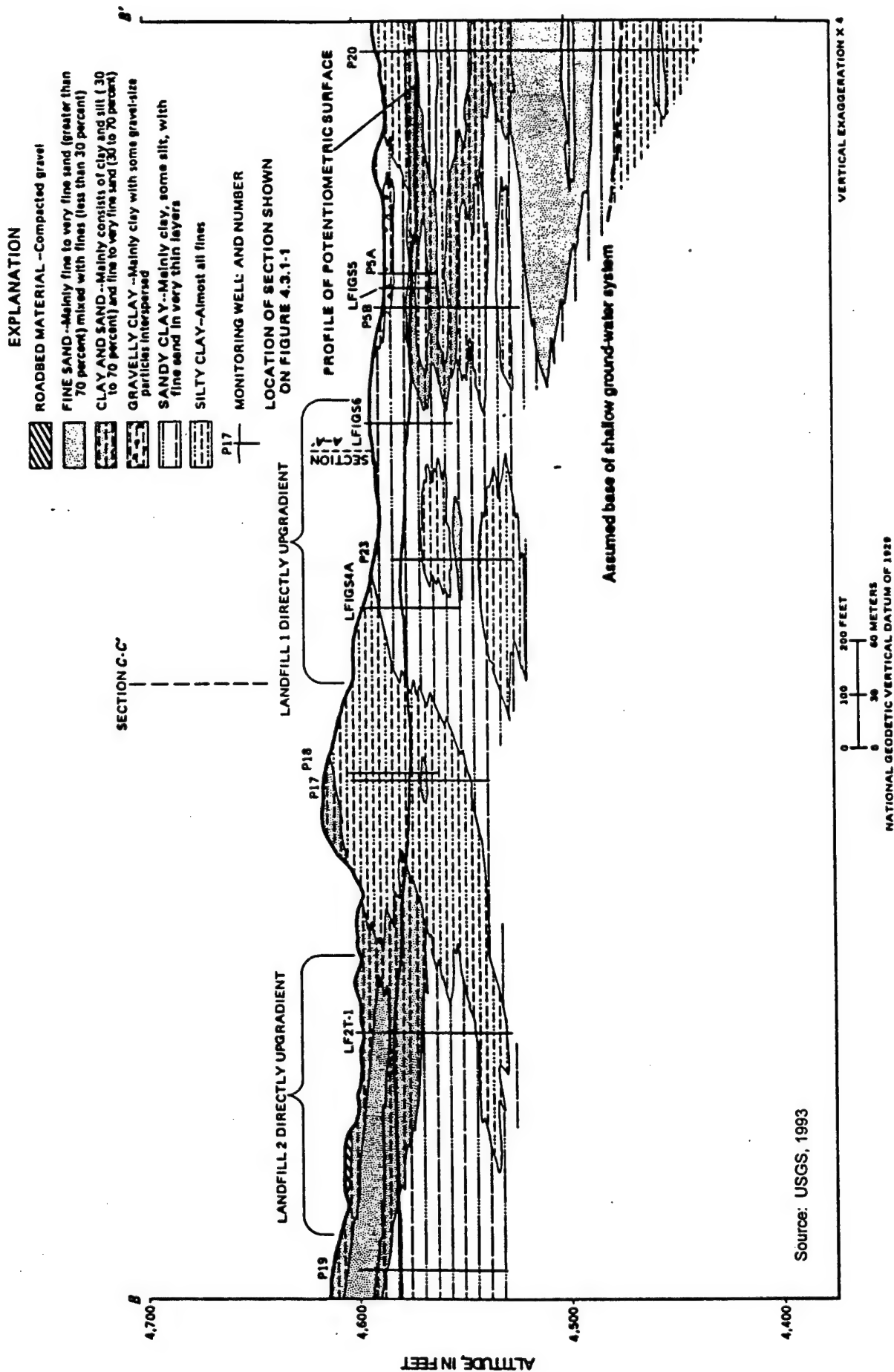


Figure 2.5 --Lateral variation in lithologic character in the first 60 to 80 feet below land surface in the area of Operable Unit 4.

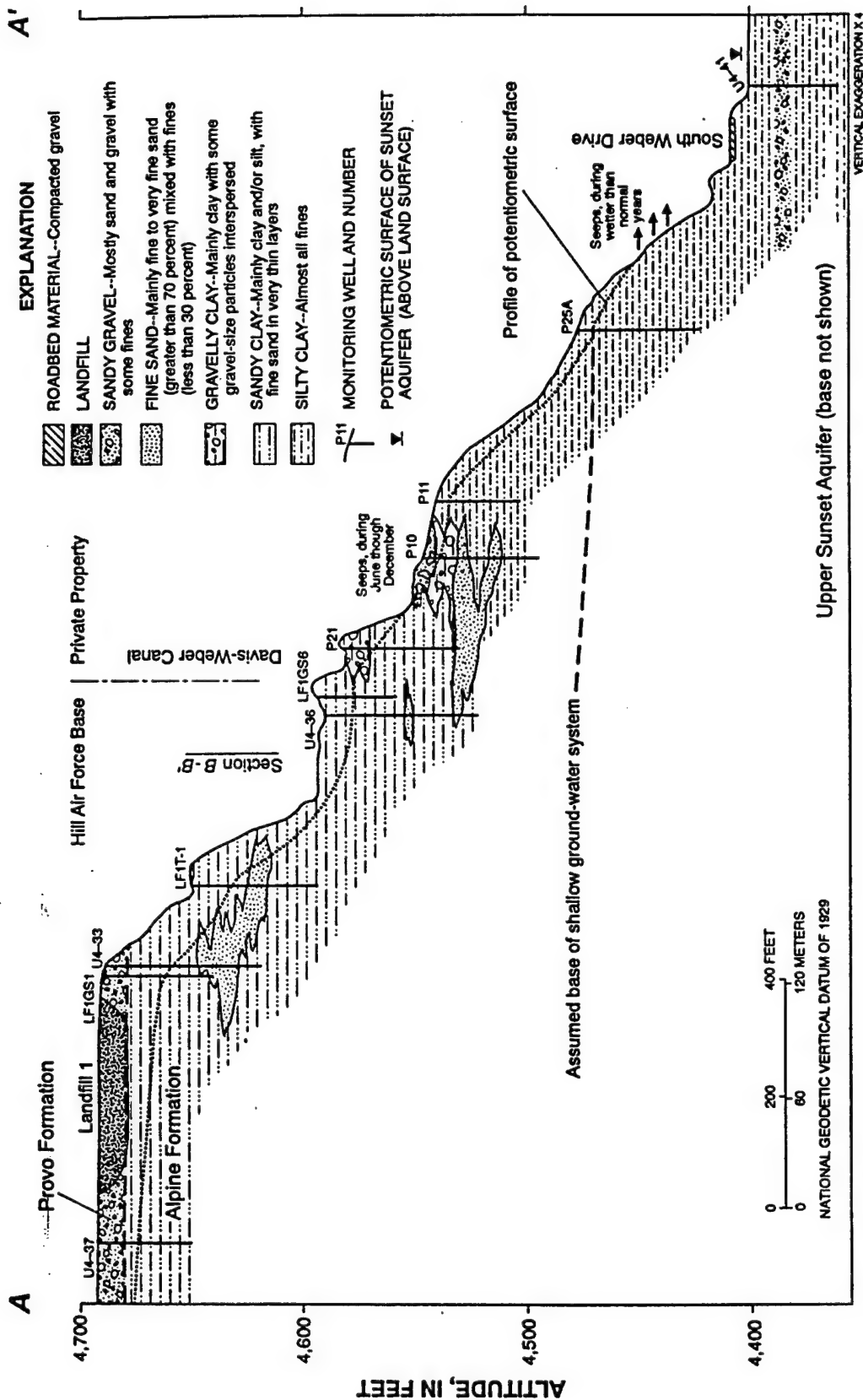
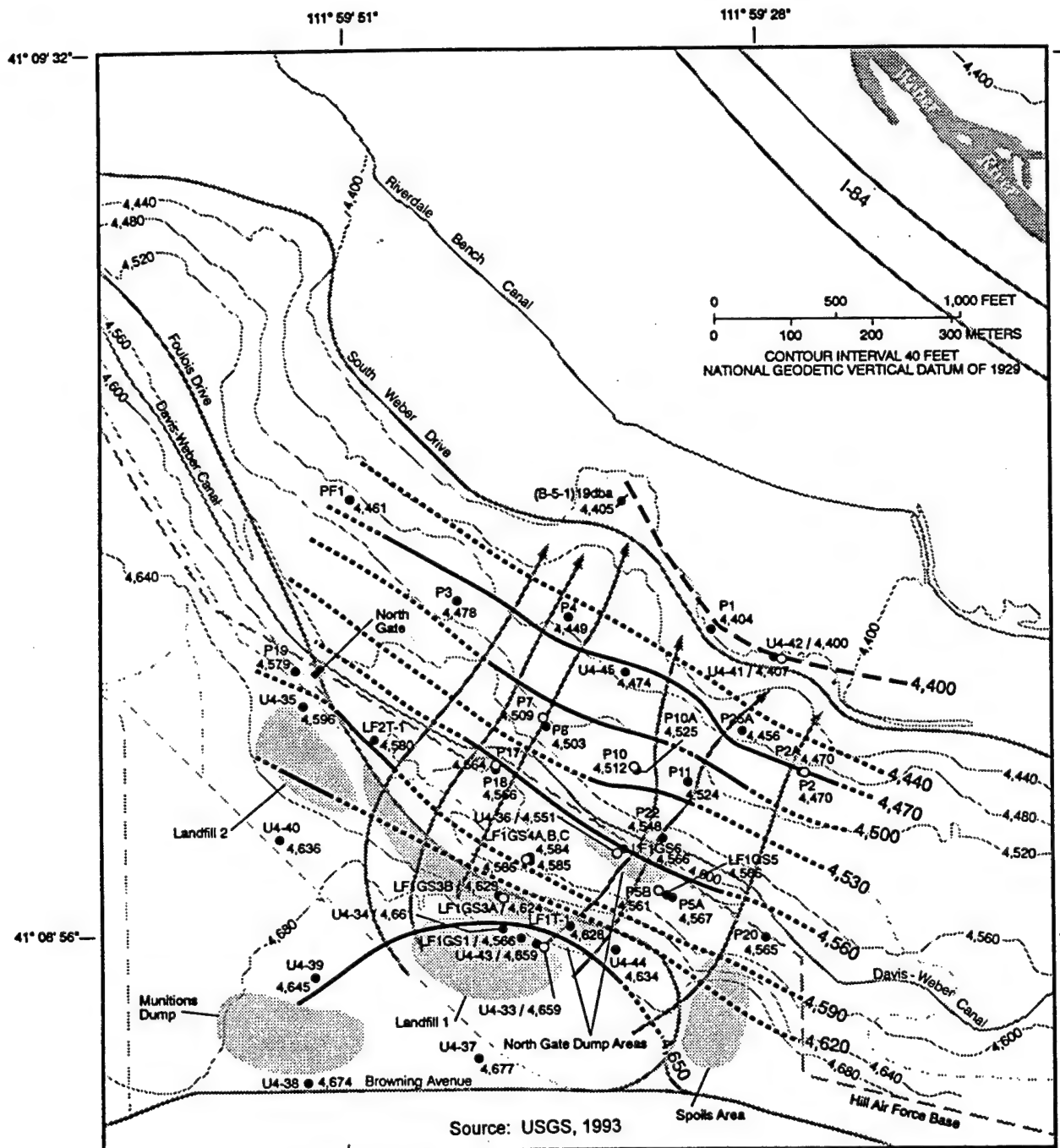


Figure 2.6--Lateral variation in lithologic character in the first 35 to 70 feet below land surface near landfill 1 along section A-A' (see figure 4.3.1-1, for location of A-A').



EXPLANATION

POTENTIOMETRIC CONTOUR--Shows altitude in feet above sea level that water level would have stood in wells (July 1992). Dashed where approximate. Contour interval 30 feet, except for Sunset aquifer

-- 4,530 Shallow ground water

-- 4,400 Sunset aquifer (conforms with Feth and others' (1966, plate 6) contour map of the Sunset aquifer)

→ GENERAL DIRECTION OF GROUND-WATER MOVEMENT

--- HILL AIR FORCE BASE BOUNDARY

..... IMPROVED DIRT ROAD

..... SECONDARY DIRT ROAD

(B-5-1)19dba
4,405

PRIVATE OR PUBLIC MONITORING WELL--
Number indicates altitude of water level. Letter and number indicate well designation

LF1GS5
4,566

MONITORING WELL-- Number indicates altitude of water level. Letter and number indicate well designation

U4-41 / 4,407

MONITORING WELL-- Number indicates altitude of water level in deep well of cluster. Letter and number indicate well designation

Figure 2.7 --Altitude of potentiometric surface of the shallow ground water and the Sunset aquifer in the area of Operable Unit 4.

hydraulic conductivities may vary by as much as four orders of magnitude among the subunits of the shallow groundwater system, groundwater velocities also may vary significantly. As part of an RNA evaluation, downhole flowmeters could be used to further define these parameters.

Geotechnical data for many of the boreholes indicate relatively low values of vertical hydraulic conductivity (Table A.2). In zones where horizontal and vertical hydraulic conductivity were obtained, the ratio of the horizontal to vertical was high, indicating strongly anisotropic flow conditions in this part of the shallow groundwater system (USGS, 1992). Vertical hydraulic gradients and velocities were calculated for several well pairs (Table A.3). The data show that both upward and downward vertical hydraulic gradients occur, depending on the time of year. The data also indicate that the vertical velocity is orders of magnitude less than the horizontal velocity. Additionally, upward hydraulic gradients in flood-plain sediments were confirmed from water levels in well pair U4-41 and U4-42 (USGS, 1993). On the basis of this hydrogeologic and geotechnical data, groundwater appears to be moving primarily in the shallower, upper portions of the shallow groundwater system, and vertical percolation through the subjacent lower permeability sediments appears to be limited. Also, groundwater mixing and dilution as a result of upward flow from the Sunset aquifer probably occurs in the flood-plain sediments (USGS, 1993).

2.1.3 Nature and Extent of Contamination at OU 4

The following discussion focuses on groundwater contamination beneath OU 4 and provides a summary of the nature, extent, and concentrations of contamination near the source area(s) and in hydraulically downgradient, off-base locations.

The RI samples were analyzed using EPA SW846 methods, E methods, and A methods for anions. The data were validated pertaining to adherence to field and laboratory QA/QC protocols but retain the laboratory-generated flags.

2.1.3.1 Soil Contamination

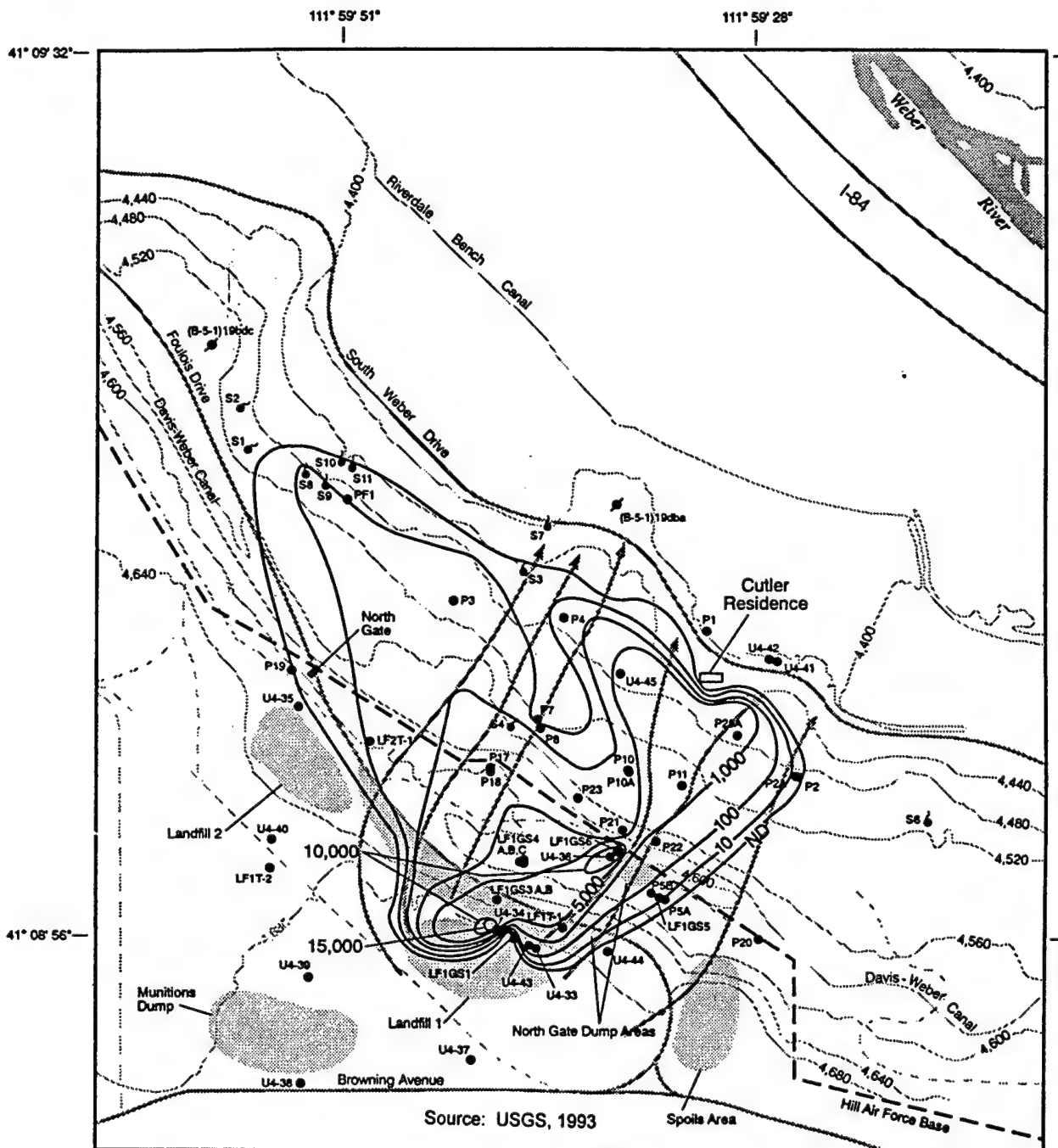
The primary source of the TCE in groundwater at OU 4 appears to be Landfill 1 (USGS, 1992). This conclusion was based on upgradient and downgradient concentrations in groundwater, and soil gas surveys. Soil contamination extended over a very limited area at Landfill 1, and the analyses did not identify residual TCE in soil. The soil gas survey results essentially coincided with the extent of groundwater contamination.

2.1.3.2 Groundwater Contamination

The groundwater plume with isoconcentrations of TCE (1986-1992) is shown in Figure 2.8. A higher concentration tongue of the plume containing between 1,000 and 5,000 micrograms per liter (ug/L) extends downgradient about 800 feet from the Base boundary nearly to South Weber Drive. The maximum concentration of TCE on-base was 18,000 ug/L near the Base boundary, whereas, the maximum concentration off-base was 2,800 ug/L. Apparently, non-aqueous phase liquid (NAPL) was not detected in the high concentration areas.

Groundwater contamination beneath OU 4 appears to be constrained to the near-surface hillside sediments in the upper part of the shallow groundwater system. The saturated thickness of TCE contaminated groundwater ranges from about 10 to 30 feet as shown in the profile of section A-A' (Figure 2.9). The TCE present near the Base boundary is thought to have originated and migrated from the Landfill 1 source area (USGS, 1993). As shown in Figure 2.9, the temporal variations of TCE in the two selected monitoring wells show decreasing upgradient concentrations, and increasing then decreasing concentrations at the Base boundary. This pattern suggests that the contaminant center of mass may be moving downgradient. A profile of TCE-contaminated groundwater along section B-B', perpendicular to groundwater flow, is provided in Figure 2.10. The profile of TCE along the downgradient flowpath of section C-C' is shown in Figure 2.11. The contaminant profiles show the concentrations of TCE abruptly decrease with depth, perhaps due to the fining downward sequence of sediments and the lower hydraulic conductivity with depth. The lithologies of contaminant profiles A-A' and B-B' are provided in Figures 2.5 and 2.6.

Organic compounds detected during the RI, and from bi-annual sampling since the RI, are provided in the Table B.1, Appendix B. The post-RI data in this table (1993-1995) have not been published and are subject to revision. Besides TCE, the only CAH of relative importance to RNA to be detected with any regularity is 1,2-dichloroethene (1,2-DCE). However, where detected, 1,2-DCE is generally detected at rather low concentrations relative to TCE, and the temporal frequency of detection is inconsistent. The distribution of DCE relative to TCE can provide an indication of ongoing biodegradation of TCE. In particular, the distribution of *cis* 1,2-DCE is most useful, because this isomer is preferentially produced through the biodegradation of TCE (Bouwer, 1994). Some 1,2-DCE in shallow groundwater is a preliminary indication that some TCE is being degraded to 1,2-DCE. Because TCE is elevated at the site, the detection limits of many of the other compounds were quite high; therefore, the non-



EXPLANATION

- 100 — LINE OF EQUAL TRICHLOROETHYLENE (TCE) CONCENTRATION, 1986-92--Concentration in micrograms per liter. Interval is variable. "ND", not detected. Maximum contaminant level for TCE is 5 micrograms per liter. At sites with well clusters, the shallow well of the cluster was used
- ← GENERAL DIRECTION OF GROUND-WATER MOVEMENT
- - - HILL AIR FORCE BASE BOUNDARY
- · - · - IMPROVED DIRT ROAD
- · - · - SECONDARY DIRT ROAD
- PF1 MONITORING WELL AND NUMBER
- (B-5-1)19dba PRIVATE OR PUBLIC WELL AND NUMBER
- S4 SEEP AND NUMBER

0 500 1,000 FEET
0 100 200 300 METERS
CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 2.8--Maximum concentrations of trichloroethylene in shallow ground water in the area of Operable Unit 4.

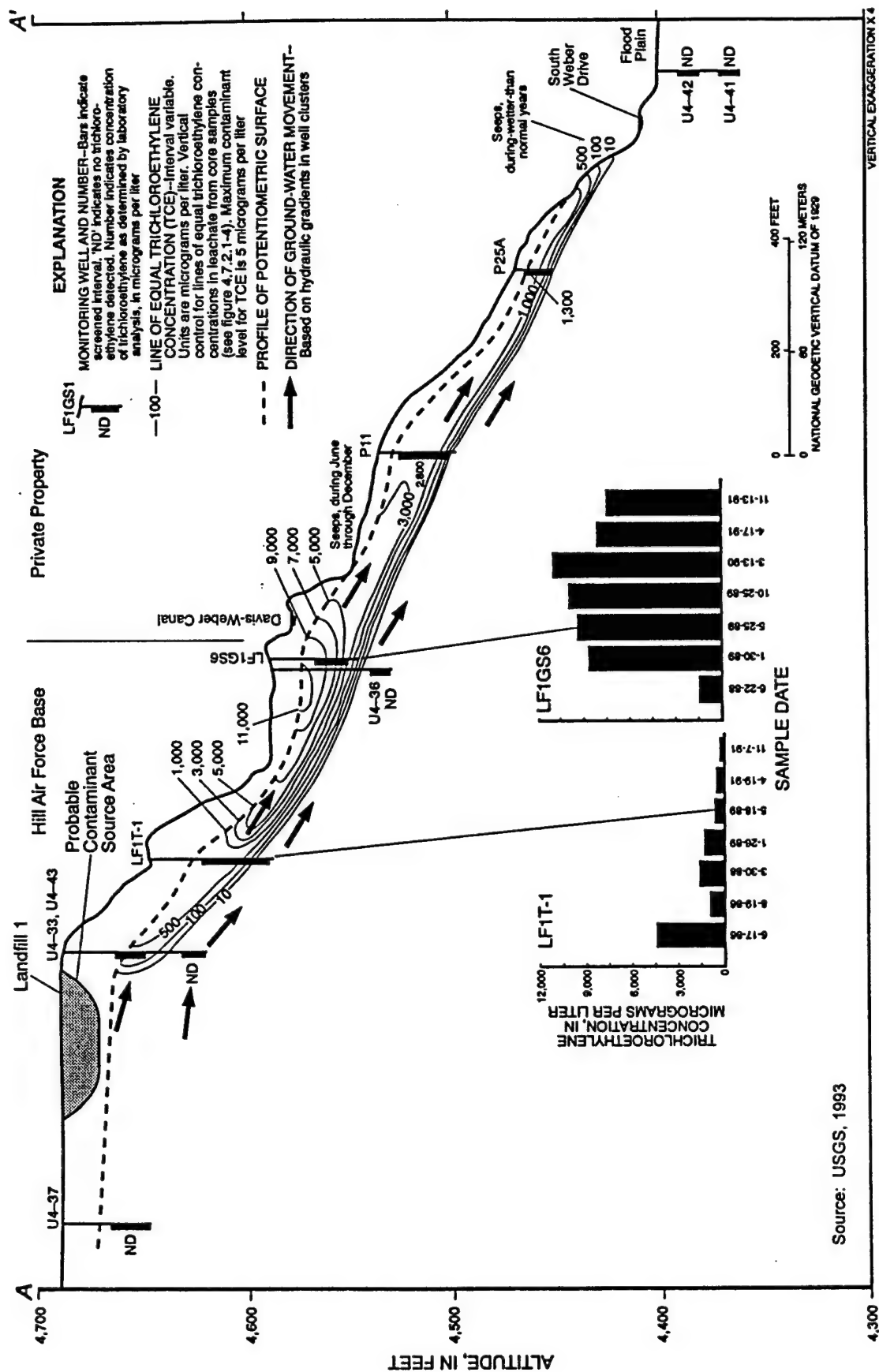


Figure 2.9 --Vertical, lateral, and temporal variations of trichloroethylene concentration in ground water along section A-A', 1986-92, in the area of Operable Unit 4.

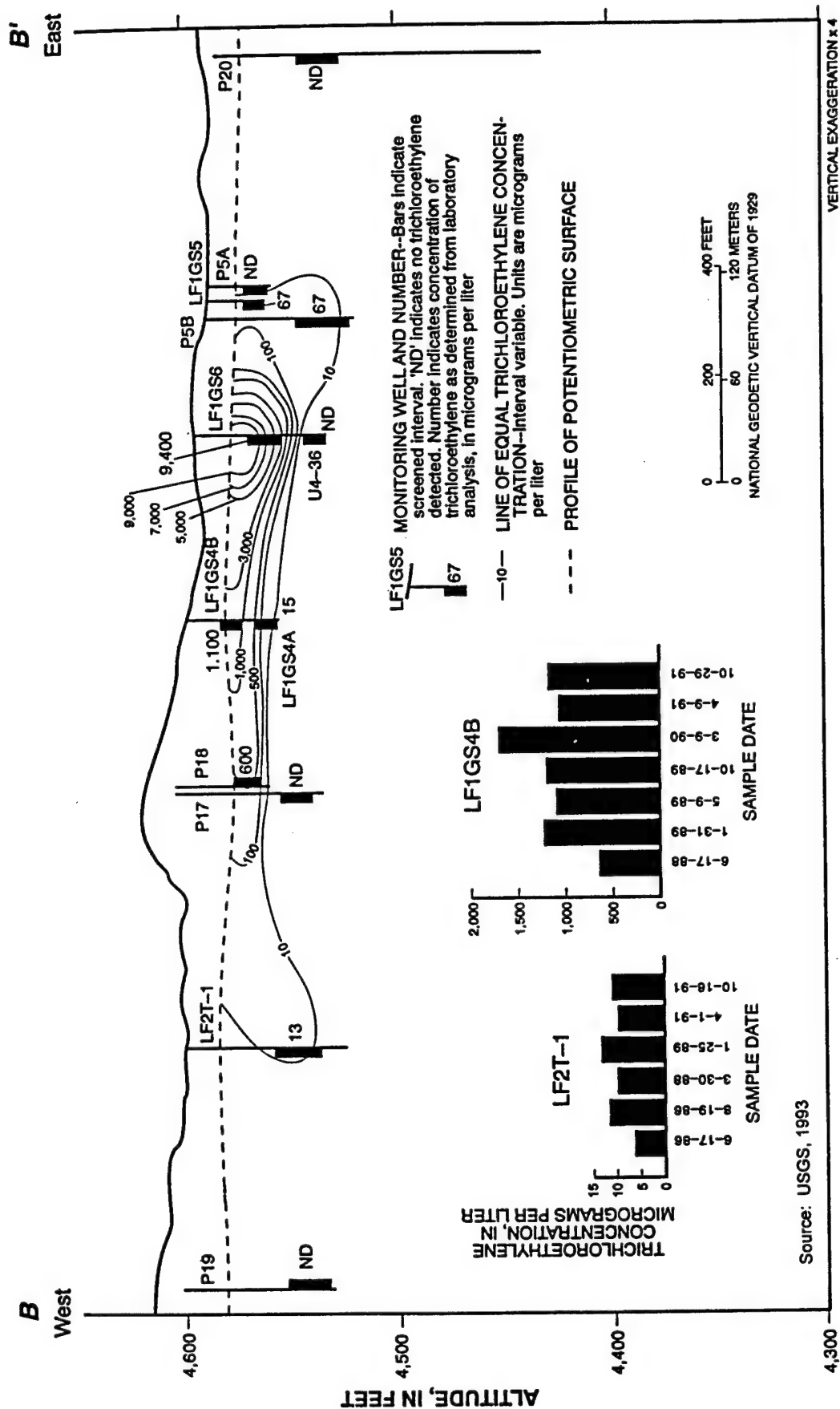


Figure 2.10 --Vertical, lateral, and temporal variations of trichloroethylene concentration in ground water along section B-B', 1986-92, in the area of Operable Unit 4.

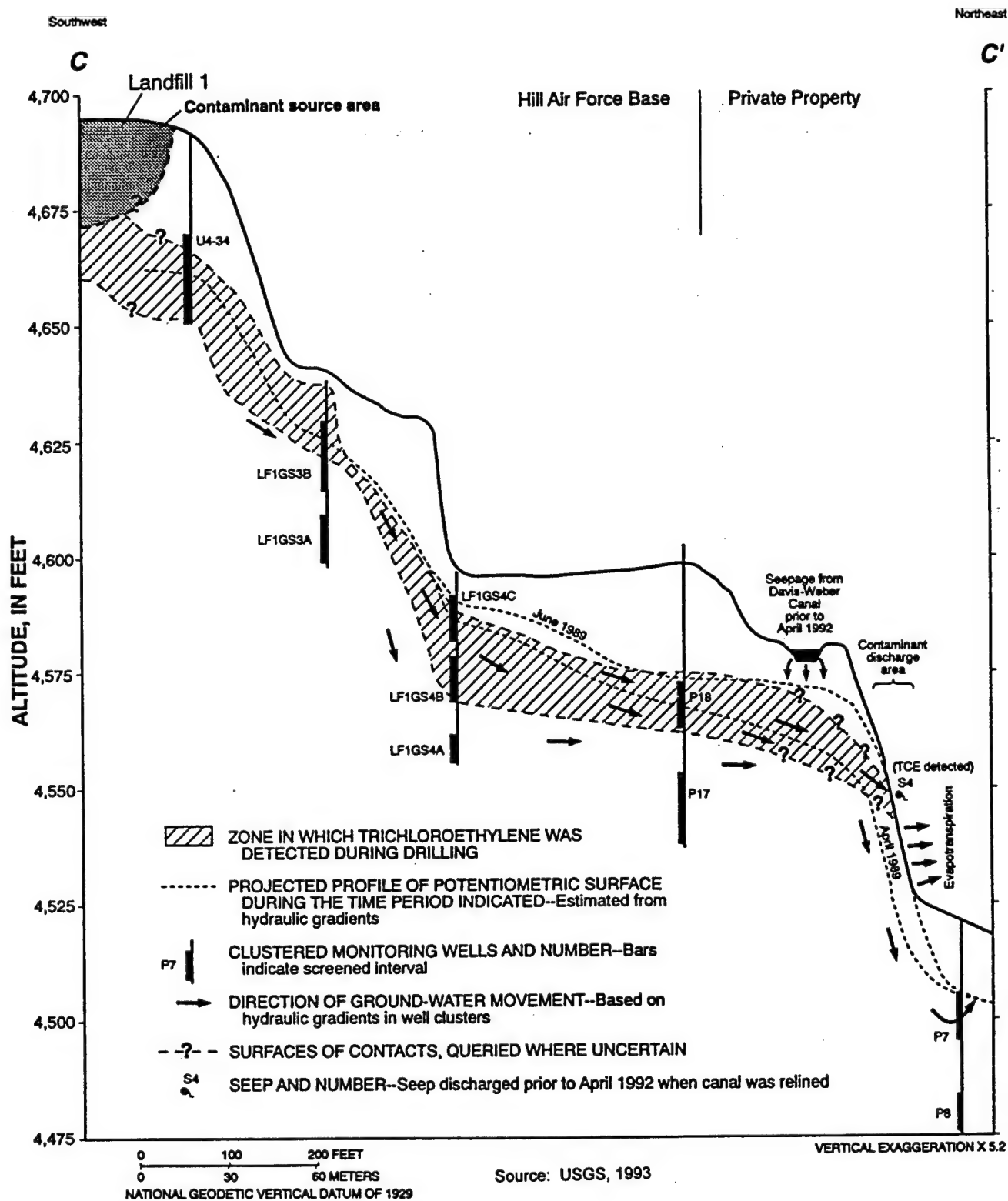


Figure 2.11 --Approximate movement of trichloroethylene along section C-C' from probable contaminant source to discharge location in the area of Operable Unit 4.

detection of other compounds may not preclude their actual presence. To confirm the existence of TCE degradation products such as 1,2-DCE and vinyl chloride (VC), lower detection limits for these CAHs will be necessary for future analyses. Apparently, VC has never been detected in OU 4 groundwater.

The TCE plume as of September 1994 is shown in Figure 2.12 (Montgomery Watson, 1995). Based on this figure, dimensions of the plume do not appear to have changed much in the two years subsequent to the RI. Also, the original USGS nomenclature for springs and wells had been changed, and some additional monitoring wells had been installed since the RI. The locations of the horizontal drains that passively collect contaminated groundwater are shown in the figure (refer to Subsection 1.3).

Elevated concentrations of sulfate also were detected in OU 4 groundwater. Concentrations of sulfate exceeding 100 mg/L coincide with areas of higher TCE in groundwater (Figure 2.13). The source of the sulfate is thought to be gypsum board disposed in Landfill 1 (USGS, 1992).

2.1.3.3 Contaminant Transport and Preferential Pathways

The apparent, primary transport pathway at OU 4 is leaching from Landfill 1 into the soil/unsaturated zone, to shallow on-base groundwater, then to off-base shallow groundwater and seeps. The analytical data for some seeps at the base of the hillside indicate that the plume is discharging via this pathway. Apparently, the leading edge of the plume is stable and discharging, and the plume is no longer increasing in size. Contamination has not been detected in shallow or deeper groundwater in the off-base floodplain.

Preferential contaminant migration pathways may exist based on the plume morphology. The higher concentrations of TCE and sulfate are channeled across the Base boundary through a narrow zone downgradient of LF1GS6 (Figure 2.8 and 2.9). This pathway is probably favored due to subsurface geologic and/or hydraulic controls at the Base boundary. Also, apparent cross-gradient migration may be occurring in the far downgradient, off-base vicinity of U4-45 and P4 (Figure 2.8 and Figure 2.13). Increasing concentrations of sulfate in well P4 may indicate that more northerly movement is occurring in preferential flow paths between these wells (USGS, 1993). A lobe of lower concentration groundwater contamination that stretches to the northwest is observed in the plume (Figures 2.8 and 2.12). This lobe may result from a secondary source area near Landfill 2 (OU 4 project manager, personal communication). Discharge appears to be occurring in the downgradient areas at this portion of the plume via springs and seeps. As discussed previously, preferential vertical migration appears to be limited because of the fine-grained sediments and lower hydraulic conductivity with depth.

EXPLANATION

- ◆ Deep monitoring well location
- ◆ 4-inch monitoring well location
- ◆ 2-inch monitoring well location
- CPT location
- - - Hill AFB Property boundary
- ~ Ground surface elevation contour (feet, NGVD)
- ~ Horizontal drain set
- ~ TCE Isoconcentration (µg/l)
- ~ TCE Isoconcentration extent uncertain
- ~ TCE concentrations (µg/l)
- ~ TCE non-detectable (<5 µg/l)

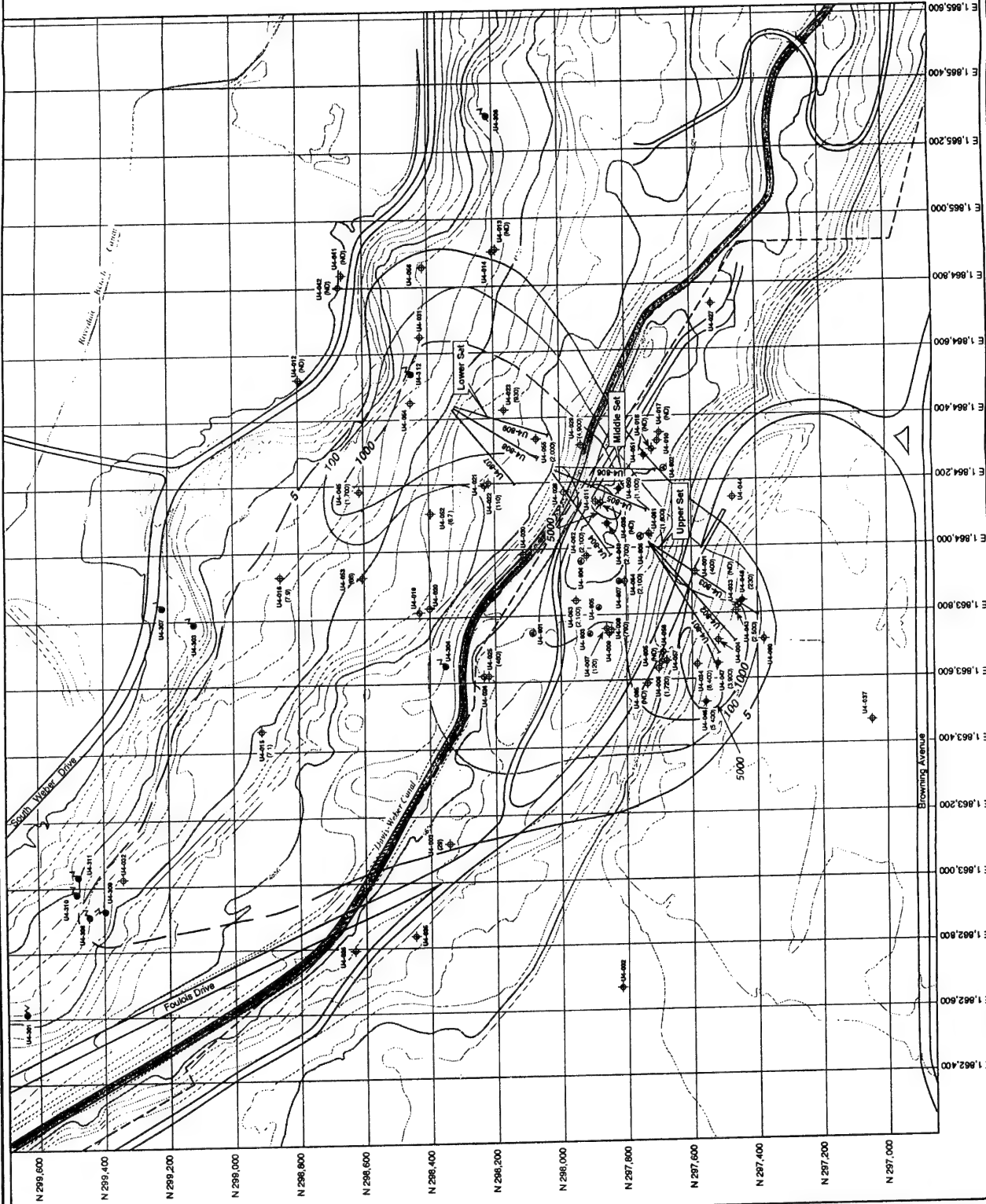
Source: Montgomery Watson, 1995

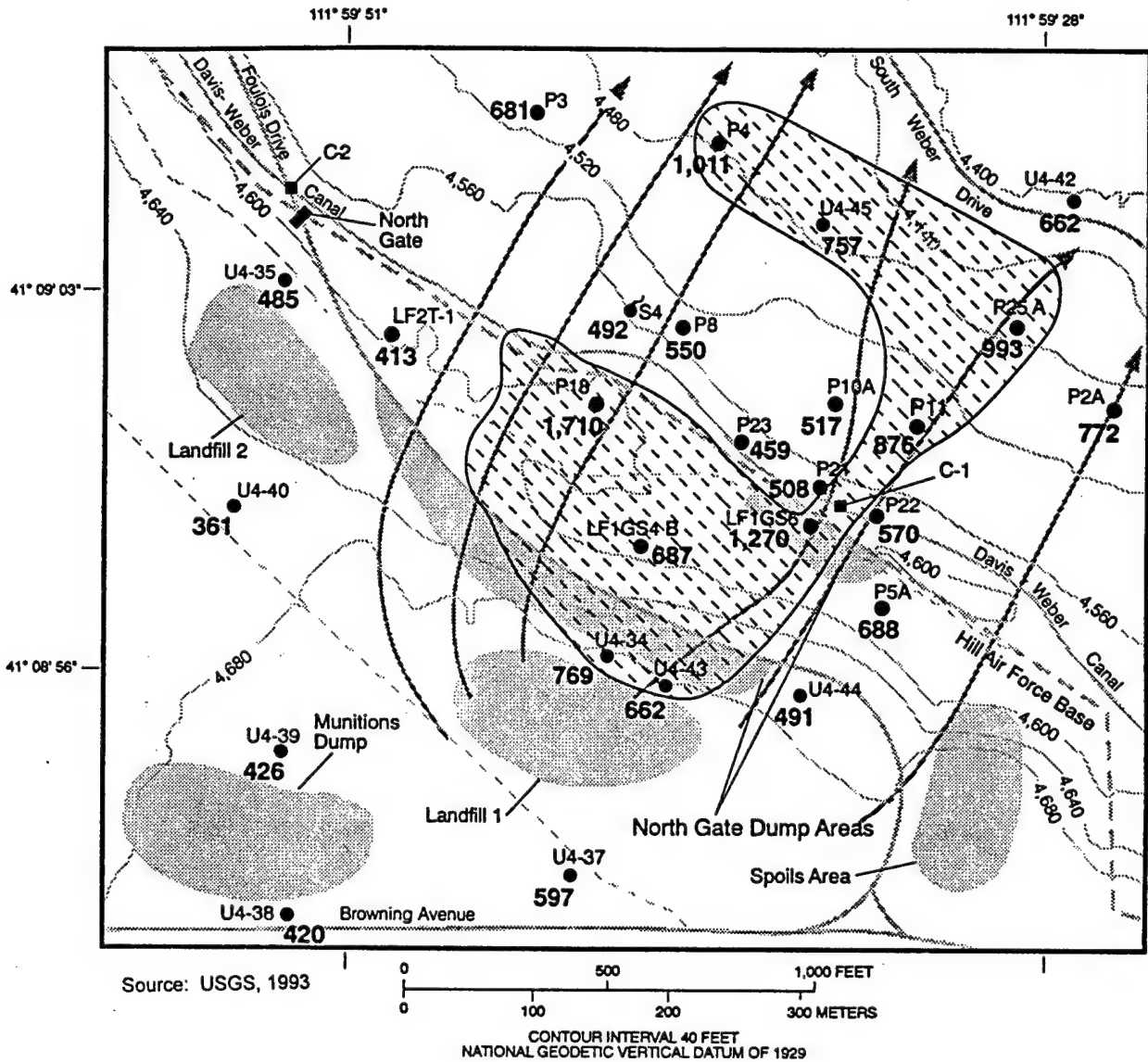


0 300
Scale in Feet

HILL AIR FORCE BASE OPERABLE UNIT 4 TCE CONCENTRATIONS MARCH - SEPTEMBER 1994 FIGURE 2.12

2-23





EXPLANATION

- AREA WHERE SULFATE CONCENTRATION EXCEEDS 100 MILLIGRAMS PER LITER--At sites with well clusters, the average concentration from the shallow well was used
- GENERAL DIRECTION OF GROUND-WATER MOVEMENT
- HILL AIR FORCE BASE BOUNDARY
- IMPROVED DIRT ROAD
- SECONDARY DIRT ROAD
- MONITORING WELL AND NUMBER--Value represents the average dissolved-solids concentration in milligrams per liter. At sites with well clusters, the average concentration from the shallow well was used
- SEEP AND NUMBER
- CANAL SAMPLING SITE AND NUMBER

Figure 2.13 --Concentration of dissolved solids in water and area where the concentration of sulfate exceeds 100 milligrams per liter in the area of Operable Unit 4.

The average linear velocity (advection only) was 0.36 ft/day along the downgradient path between LF1GS6 and P25A, using an average hydraulic conductivity of 1 ft/day, a hydraulic gradient of 0.15 ft/ft, and porosity of 0.42 (USGS, 1992). The groundwater flow rate for the entire plume width (1,300 feet) was estimated at 20 gallons per minute, using the data above and a saturated thickness of 20 feet (Montgomery Watson, 1995). The mass flux of TCE crossing the Base boundary in the narrow, high concentration zone is estimated to be 17.8 grams/day or 14 pounds/year using the hydraulic conductivity, hydraulic gradient, and porosity given above. This estimate is based on an average plume concentration of 5,000 ug/L for a width of 100 feet, and a groundwater flux per unit width of 22.4 gal/day/ft (see Figures 2.8 and 2.9). The flux calculation also assumes a saturated thickness of 20 feet.

2.1.4 Groundwater Geochemistry

Stiff diagrams showing the mass balance of major cations and anions in shallow groundwater along the downgradient flowpath is shown in Figure 2.14. The dominant ions in the shallow groundwater system are magnesium and bicarbonate. A lower TDS sodium-bicarbonate type water at valley well P1 is considered to be indicative of water in the upper Sunset Aquifer. Apparently, deeper water in the upper Sunset Aquifer is migrating upward and mixing with shallow groundwater in the Weber River flood plain deposits (USGS, 1992 and 1993). Therefore, if groundwater contamination reaches the flood plain deposits it would be subject to dilution, and the chance of contamination ever reaching the Weber River is very minimal (USGS, 1993).

The inorganic chemistry of OU 4 groundwater is provided in Appendix C and Appendix D. The analysis for metals is for filtered samples (USGS, 1992). Trace metals such as iron and manganese were not analyzed consistently, both spatially and temporally, and these metals were primarily analyzed during the RI phase of sampling at OU 4 (Appendix C). The temporal variation of nitrate and sulfate is well documented (Appendix D). Dissolved oxygen and oxidation/reduction potential (redox potential) were not measured. The pH was generally in the 7 to 8 pH units range (Appendix D).

Selected ions and metals in groundwater along sections A-A', B-B', and C-C' are shown in Figures 2.15, 2.16, and 2.17, respectively. These data are for one of the 1992 sampling events unless otherwise noted on the figures. Generally, concentrations of dissolved (reduced) iron and manganese are relatively low. The presence of iron and manganese at some locations, however, may indicate locally reducing conditions. The presence of some nitrate suggests that conditions are not strongly reducing (nitrate is

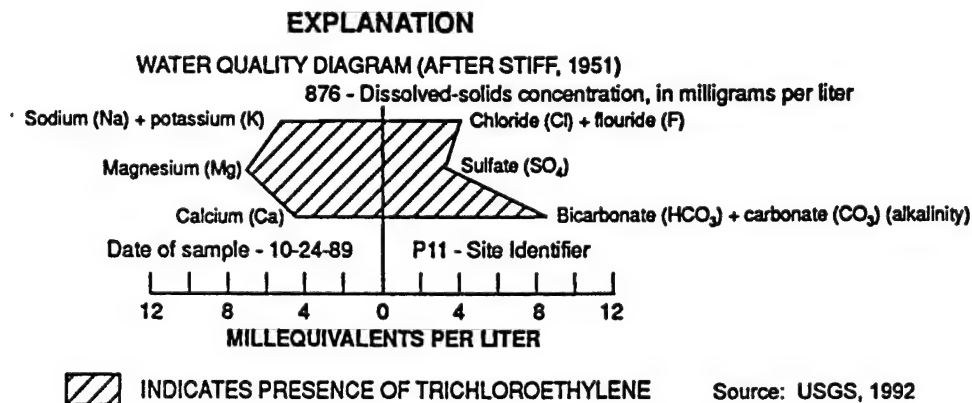
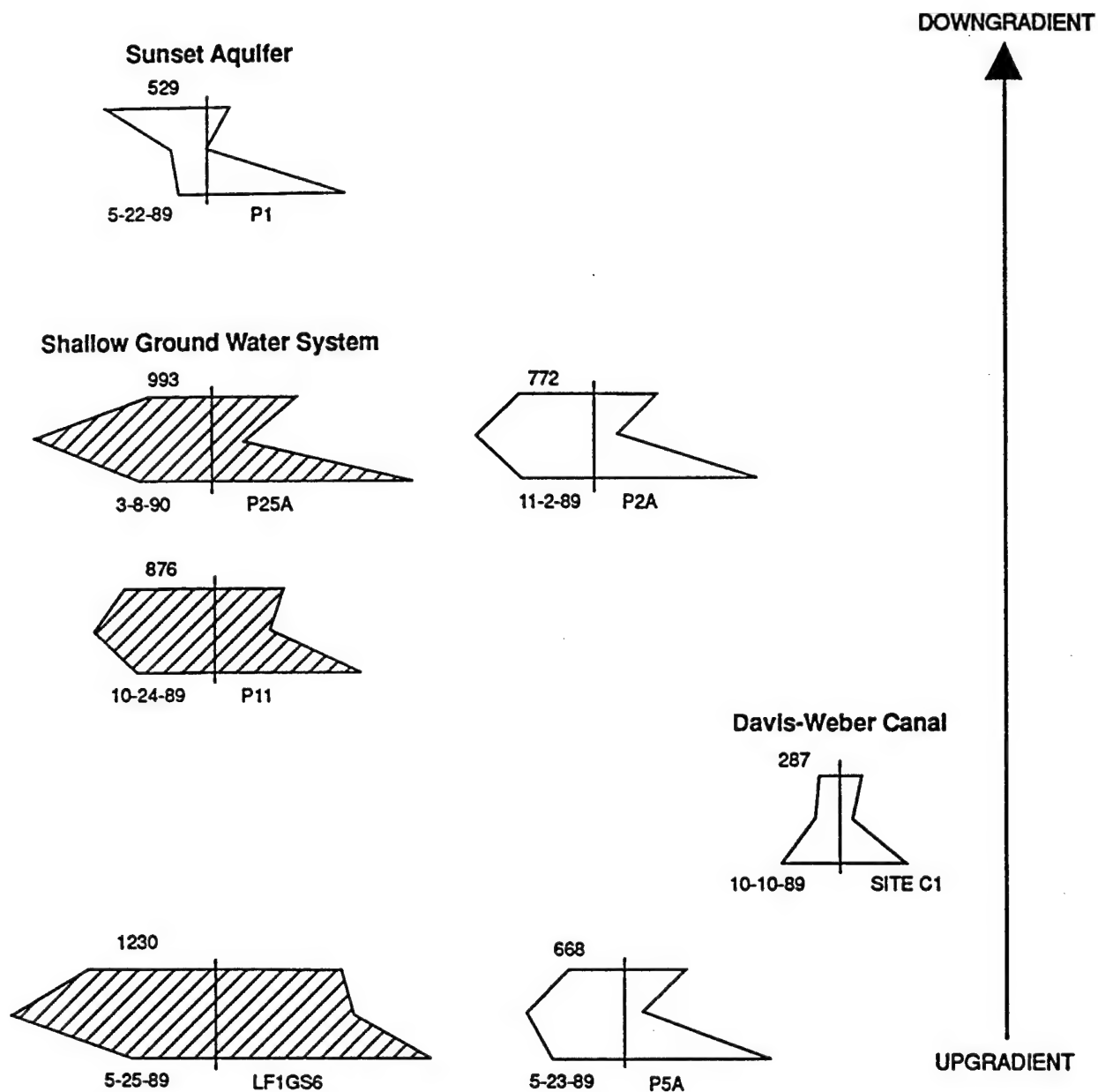
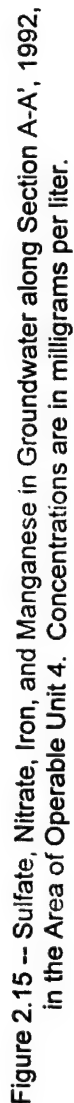


Figure 2.14 --Water-quality diagrams for selected wells and Davis-Weber Canal in the area of Operable Unit 4.



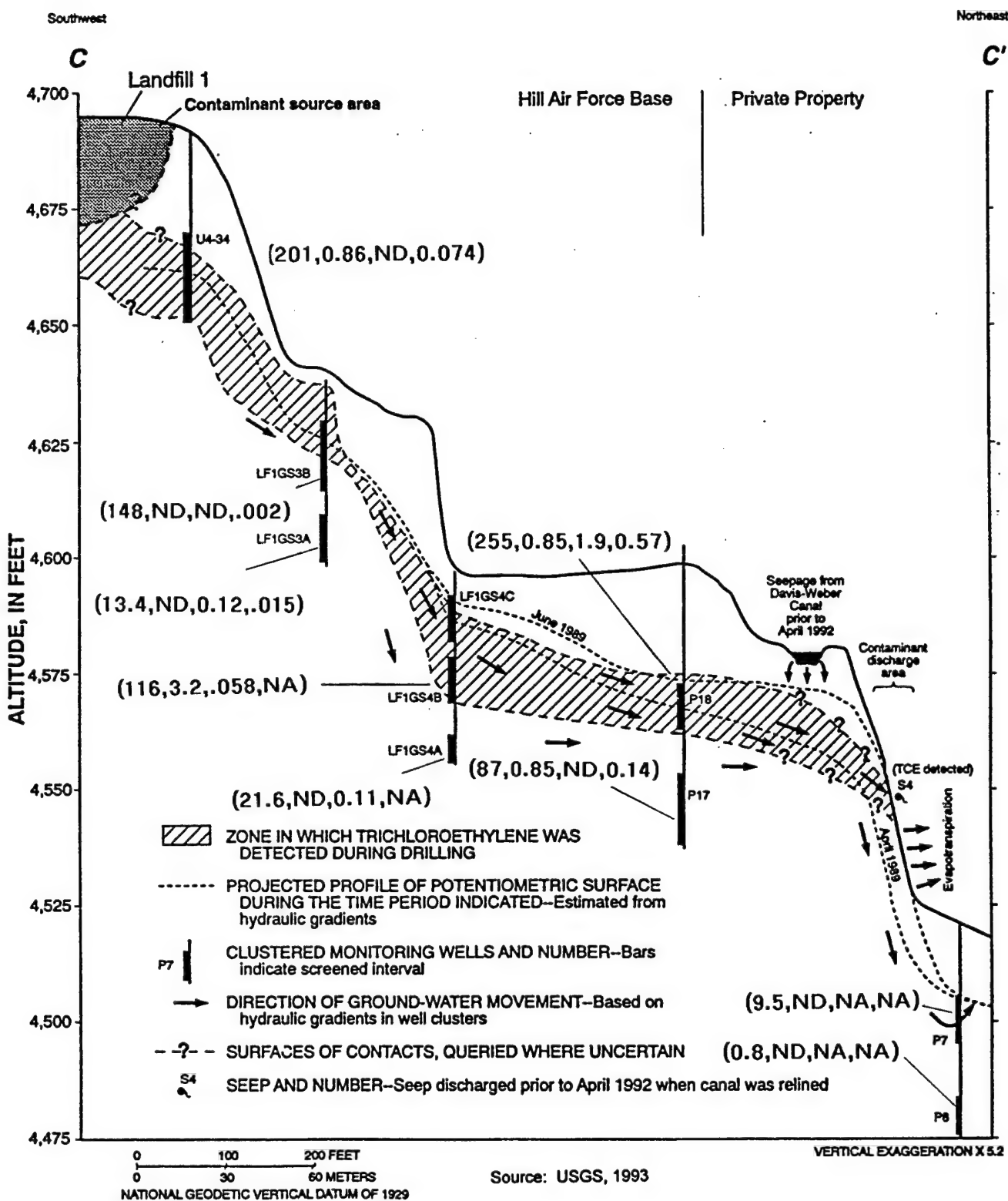


Figure 2.17 – Sulfate, Nitrate, Iron, and Manganese in Groundwater along Section C-C', 1992, in the Area of Operable Unit 4. Concentrations are in milligrams per liter.

generally depleted under reducing conditions strong enough to produce hydrogen sulfide). The data tentatively indicate that environmental conditions may be more strongly reducing with depth, because higher concentrations of reduced metals appear to be present and nitrate is not detected or is depleted in the deeper monitoring wells. There may be some downgradient nitrate depletion along the A-A' flowpath (Figure 2.15). Abundant sulfate is present throughout the entire TCE plume.

2.2 DEVELOPMENT OF CONCEPTUAL MODELS

A conceptual model of groundwater flow is a three-dimensional representation of a hydrogeologic system based on available geological, hydrological, climatological, and geochemical data. A site-specific conceptual model of groundwater flow is developed to provide an understanding of the mechanisms controlling contaminant transport. A conceptual model of RNA is developed to provide an understanding of the fate processes that bring about a total reduction in contaminant mass. Combined, the preliminary conceptual model of groundwater flow and RNA provides a foundation for formulating decisions regarding additional data collection and the potential for intrinsic remediation. The conceptual model for OU 4 will be used to aid in selecting additional data collection points and to identify appropriate data needs for modeling natural attenuation of CAHs.

Successful conceptual model development involves:

- Defining the problem to be solved;
- Integrating available data, including
 - Local geologic and topographic data,
 - Hydraulic data,
 - Site stratigraphic data
 - Primary contaminant and daughter product concentration and distribution data,
 - Geochemical concentration and distribution data,
 - Distribution and values of DO, redox potential, pH, etc., and
 - Geotechnical data (e.g., native organic carbon, etc.)
- Evaluating contaminant fate and transport characteristics;
- Identifying contaminant preferential pathways;
- Identifying the occurrence and types of active biodegradation;

- Identifying potential receptors and exposure points; and
- Determining additional data requirements.

2.2.1 RNA and Solute Transport Models

After a site has been adequately characterized, fate and transport analyses can be performed to determine the potential for contaminant migration and human and ecological receptor pathway completion. Groundwater flow and solute transport models have proven useful for predicting plume migration and contaminant attenuation by natural biodegradation. Analytical and numerical models are available for modeling the fate and transport of CAHs under the influence of advection, dispersion, sorption, and natural aerobic and anaerobic biodegradation. Analytical models derived from advection-dispersion equations [e.g., models such as those presented by Wexler (1992) and van Genuchten and Alves (1982)] may be useful. However, because CAH biodegradation may be the result of different processes in different locations, it may be necessary to use a numerical model to incorporate spatial variability in contaminant decay rates.

An accurate estimate of the potential for natural biodegradation of chlorinated compounds in groundwater is important to consider when determining whether groundwater contamination presents a substantial threat to human health and the environment, and when deciding what type of remedial alternative will be most cost effective in eliminating or abating these threats. Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms degrade a variety of fuel hydrocarbons and chlorinated solvents (Lee, 1988; McCarty *et al.*, 1992). The following section discusses the biodegradation of CAHs.

2.2.2 Biodegradation of CAHs

Chlorinated solvents can be transformed, directly or indirectly, by biological processes (e.g., Bouwer *et al.*, 1981; Wilson and Wilson, 1985; Miller and Guengerich, 1982; Nelson *et al.*, 1986; Bouwer and Wright, 1988; Little *et al.*, 1988; Mayer *et al.*, 1988; Arciero *et al.*, 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom *et al.*, 1990; Harker and Kim, 1990; Alvarez-Cohen and McCarty, 1991a, 1991b; DeStefano *et al.*, 1991; Henry, 1991; McCarty *et al.*, 1992; Hartmans and de Bont, 1992; McCarty and Semprini, 1994; Vogel, 1994). CAHs may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme

fortuitously produced during an unrelated process. At a given site, one or any combination of these processes may be operating, although at many sites biodegradation of CAHs as electron acceptors appears to be the most important.

In a pristine aquifer, native organic carbon is utilized as an electron donor and DO is utilized first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbons or low-molecular-weight CAHs) is present, it also will be utilized as an electron donor. After the DO is consumed or in the absence of DO, organotrophic (derive carbon from organic matter) anaerobic microorganisms typically use native electron acceptors (as available) to facilitate biological reactions in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how CAH biodegradation is occurring. In addition, because CAHs may be used as electron acceptors or electron donors (in competition with other acceptors or donors), isopleth maps showing the distribution of these compounds will also provide evidence of the types of biodegradation processes acting at a site.

As with BTEX, the driving force behind redox reactions resulting in CAH degradation is electron transfer. Although thermodynamically favorable, most of the reactions involved in CAH reduction and oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy. A more complete description of the main types of biodegradation reactions affecting CAHs is presented in the following subsections.

2.2.2.1 Electron Acceptor Reactions (Reductive Dehalogenation)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is removed and replaced with a hydrogen atom. Figure 2.18 illustrates the transformation of chlorinated ethenes via reductive dehalogenation. In general, reductive dehalogenation occurs by sequential dehalogenation from tetrachloroethene (PCE) to TCE to DCE to vinyl chloride (VC) to ethene. Depending on environmental conditions, this sequence may be interrupted, with other processes then acting on the products. During reductive dehalogenation, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE

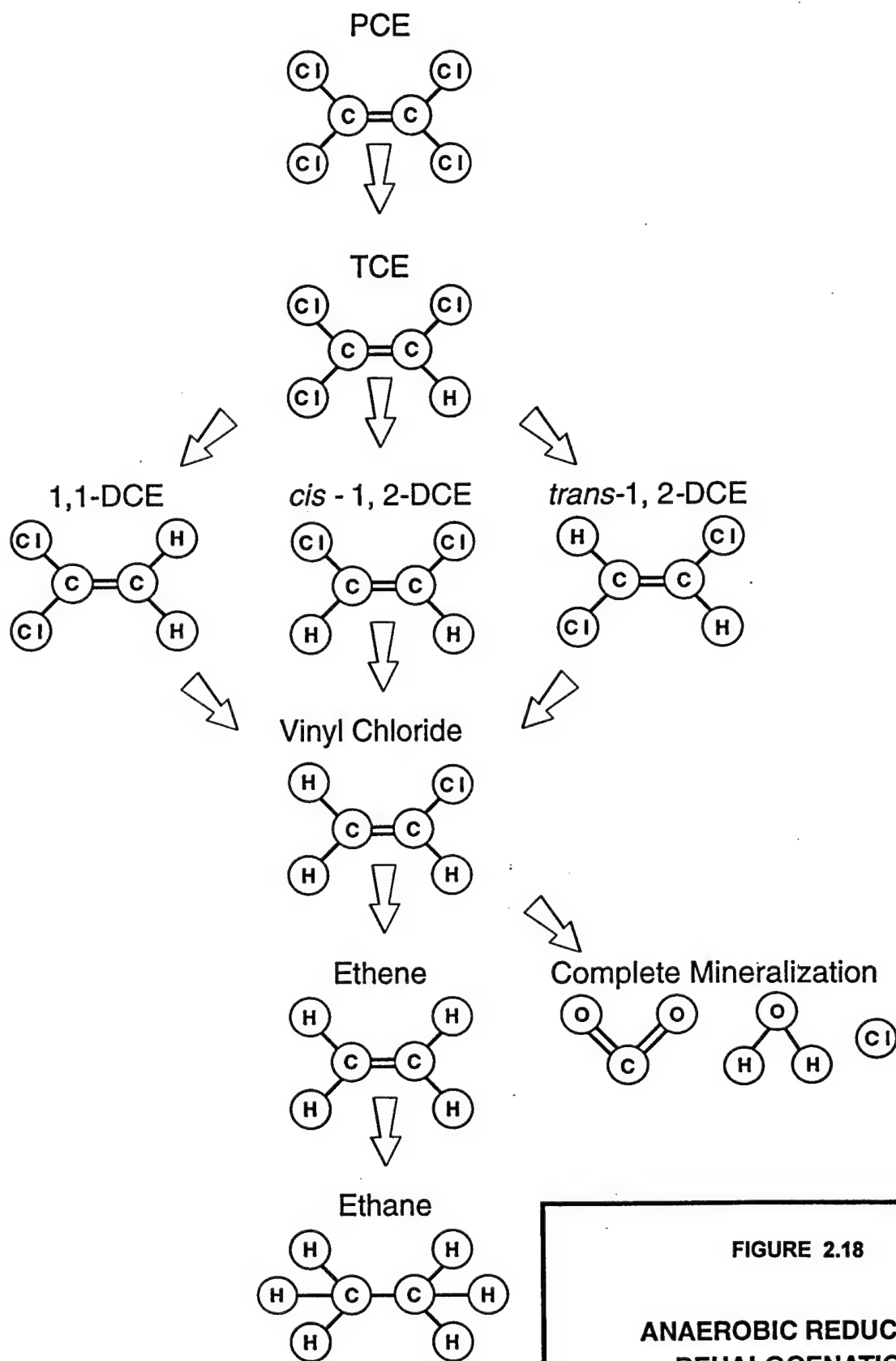


FIGURE 2.18

**ANAEROBIC REDUCTIVE
DEHALOGENATION**

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is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers. Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

Reductive dehalogenation affects each of the chlorinated ethenes differently. Of these compounds, PCE is the most susceptible to reductive dehalogenation because it is the most oxidized. Conversely, VC is the least susceptible to reductive dehalogenation because it is the least oxidized of these compounds. The rate of reductive dehalogenation also has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in PCE and TCE plumes that are undergoing reductive dehalogenation. Reductive dehalogenation has been demonstrated under anaerobic nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994).

Because CAH compounds are used as electron acceptors, there must be an appropriate source of carbon (electron donor) for microbial growth in order for reductive dehalogenation to occur (Bouwer, 1994). Potential carbon sources can include low molecular weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, or fuel hydrocarbons. In some anaerobic conditions dihydrogen can act as an electron donor, although small concentrations of complex organic compounds are required for growth (Paul and Clark, 1989).

2.2.2.2 Electron Donor Reactions

Under aerobic conditions some CAH compounds can be utilized as the primary substrate (i.e., electron donor) in biologically mediated redox reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. In contrast to reactions in which the CAH is used as an electron acceptor, only the least oxidized CAHs can be utilized as electron donors in biologically mediated redox reactions. McCarty and Semprini (1994) describe investigations in which VC and 1,2-DCA were shown to serve as primary substrates. These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. In addition, Bradley and Chapelle (1996) show evidence of mineralization of VC under iron-reducing conditions so long as there is sufficient ferric iron available for biological processes.

Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE. Aerobic metabolism of VC may be characterized by a loss of VC mass, a decreasing molar ratio of VC to other CAH compounds, and the presence of chloromethane.

2.2.2.3 Cometabolism

When a CAH is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated redox reaction. Instead, the degradation of the CAH is catalyzed by an enzyme or cofactor that is fortuitously produced by organisms for other purposes. The organism receives no known benefit from the degradation of the CAH. In some cases, cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994).

Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. Aerobic biodegradation pathways for chlorinated ethenes are illustrated in Figure 2.19. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994). Vogel (1994) further elaborates that the cometabolism rate increases as sequential dehalogenation proceeds from TCE to VC.

In the cometabolic process, TCE is indirectly transformed by bacteria as they use BTEX or another carbon substrate to meet their energy requirements. Therefore, TCE does not enhance the degradation of BTEX or other carbon sources, nor will its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources. It is likely that depletion of suitable substrates (BTEX or other organic carbon sources) limits cometabolism of CAHs.

2.2.2.4 Behavior of Chlorinated Solvent Plumes

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of organic (native and/or anthropogenic) carbon in the aquifer, the distribution and concentration of natural electron acceptors, and the types of electron acceptors being utilized. Individual plumes may exhibit all three types of behavior in different portions of the plume. The different types of plume behavior are summarized below.

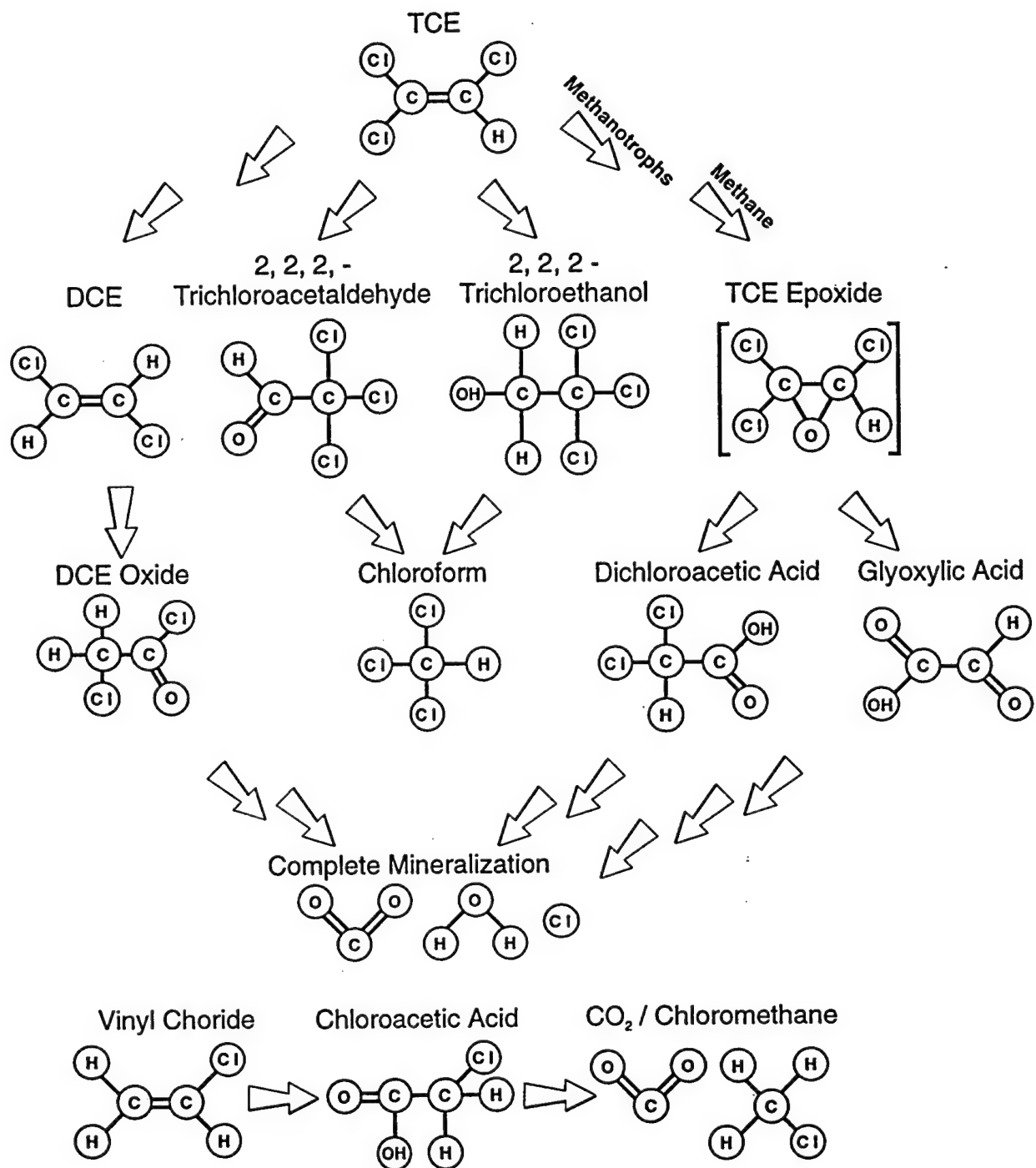


FIGURE 2.19

AEROBIC DEGRADATION

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2.2.2.4.1 Type 1 Behavior

Type 1 behavior occurs where the primary substrate is anthropogenic carbon (e.g., BTEX or landfill leachate), and this anthropogenic carbon drives reductive dehalogenation. When evaluating intrinsic remediation of a plume exhibiting type 1 behavior the following questions must be answered:

- 1) Does electron donor supply exceed demand [i.e., is the electron donor (i.e., BTEX) supply adequate]?
- 2) Will the CAH plume "strangle" before it "starves" [i.e., will it run out of CAHs (electron acceptors) before it runs out of primary substrate (anthropogenic carbon)]?
- 3) What is the role of competing electron acceptors?
- 4) Is VC oxidized, or is it reduced?

2.2.2.4.2 Type 2 Behavior

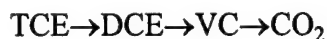
Type 2 behavior dominates in areas that are characterized by relatively high native organic carbon concentrations, and this carbon source drives reductive dehalogenation (i.e., the primary substrate for microorganism growth is native organic carbon). When evaluating intrinsic remediation of a type 2 chlorinated solvent plume, the same questions as those posed in the description of type 1 behavior must be answered.

2.2.2.4.3 Type 3 Behavior

Type 3 behavior dominates in areas that are characterized by low native and/or anthropogenic carbon concentrations, and DO concentrations that are greater than 1.0 mg/L. Under these conditions the plume is aerobic, and reductive dehalogenation will not occur. Thus there is no reductive dehalogenation of PCE, TCE, and DCE. Biodegradation of TCE and its daughter products may proceed via the much slower process of cometabolism, but will be limited by the low concentrations of native or anthropogenic carbon. The most significant natural attenuation mechanisms for the more oxidized CAHs will be advection, dispersion, and sorption. However, the less oxidized CAHs such as VC, and possibly DCE, could be oxidized under these conditions.

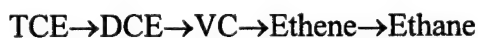
2.2.2.4.4 Mixed Behavior

As previously mentioned, a single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be beneficial for natural biodegradation of CAH plumes. For example, Wiedemeier *et al.* (1996) describe a plume at Plattsburgh AFB, New York that exhibits type 1 behavior in the source area and type 3 behavior downgradient from the source. The best scenario involves a plume in which TCE and DCE are reductively dehalogenated (type 1 or 2 behavior), then VC is oxidized (type 3 behavior), either aerobically or anaerobically (via iron reduction). VC is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in this type of plume.



In general, the TCE, DCE, and VC may attenuate at approximately the same rate, and thus these reactions may be confused with simple dilution. Note that no ethene is produced during this reaction. VC is removed from the system much faster under these conditions than it is under VC-reducing conditions.

A less desirable scenario involves a plume in which all CAHs are reductively dehalogenated (type 1 or 2 behavior). VC is reduced to ethene, which is further reduced to ethane. The following sequence of reactions occur in this type of plume.



In this type of plume, DCE and VC degrade more slowly than TCE, and thus they tend to accumulate. This type of reductive dehalogenation is the described by Freedman and Gossett (1989).

2.2.2.4.5 Abiotic Transformations

In general, abiotic transformations of CAHs are not significant relative to other natural attenuation processes. However, 1,1,1-TCA can be transformed abiotically to form 1,1-DCE (and ultimately VC) or acetic acid, although the process is relatively slow, with a half-life on the order of one year (Bouwer, 1994; Vogel, 1994). Such processes can complicate the study of CAH transformation, particularly if conditions are such that the half-life of the abiotic process is similar to that of biological processes in effect.

2.2.3 Preliminary Conceptual Model

The hydrogeology at OU 4 is generally well defined. Geologic and hydrogeologic data were shown in cross-sections A-A' and B-B' (Figures 2.5 and 2.6). The shallow deposits consist mainly of fine-grained sediments with some distinct thin layers of coarser material that are laterally discontinuous. The average hydraulic conductivity of the sediments is about 1 ft/day, but varies by four orders of magnitude. Groundwater moves in the interfingering layers of silt and sand in the shallower, upper portions of the shallow groundwater system, and the contamination is constrained to the near-surface hillside sediments. Vertical migration appears to be limited with depth by finer-grained, lower hydraulic conductivity sediments. The ratio of horizontal to vertical hydraulic conductivity indicates strong horizontal anisotropy in the sediments of the shallow groundwater system. Groundwater is very shallow along the hillside and flow is northeast and downslope toward the valley. On the basis of plume morphology, the preferential migration of groundwater contamination may be occurring within the plume (Figure 2.8). Preferential pathways probably are favored due to subsurface geologic and/or hydraulic controls. TCE apparently has leached from Landfill 1, and possibly Landfill 2, and has migrated downgradient under the influence of a steep hydraulic gradient to seeps along the hillside. The vertical profile of groundwater contamination along the hillside is well defined, and the shallow groundwater of the hillside appears to be hydraulically isolated from shallow groundwater in the valley, and thus, the deeper Sunset Aquifer. Upward vertical hydraulic gradients are present in the valley flood-plain deposits. Based on the information above, OU 4 could be modeled as an unconfined, heterogeneous, anisotropic aquifer under steady-state or transient-state flow conditions.

The CAH plume at OU 4 is well defined, and can be characterized as having a rather high contaminant mass but low volumetric flow rate. Mechanisms of RNA such as advection, dispersion, dilution, discharge, evapotranspiration, volatilization, and biodegradation probably are reducing concentrations or removing contaminant mass in the plume. The leading edge of the plume appears to be discharging to seeps located near the base of the hillside at about 4,400-ft above msl, and may be stabilized. Therefore, discharge and vadose zone processes including evapotranspiration may be more important in reducing contaminant mass in groundwater than biodegradation.

Both aerobic and anaerobic biodegradation may be occurring in the OU 4 plume but the biodegradation of CAHs may be limited. Some of the data suggest that some TCE may be reductively dehalogenated or aerobically biodegraded (cometabolism) to DCE. The formation of some 1,2-DCE and ferrous iron suggest some reductive dehalogenation is taking place; although, available nitrate and the general lack of VC indicate conditions

are not strongly reducing. Plume behavior under these conditions would be Type 1 or Type 2 depending on the source and relative abundance of carbon driving reduction dehalogenation. The primary carbon source appears to be native carbon (Table A.2); however, the amount of bioavailable carbon (electron donor) may be limiting reductive dehalogenation and cometabolism (i.e., the plume may be carbon starved). Additionally, high sulfate concentrations (a competing electron acceptor) may limit reductive dehalogenation. Most reductive dehalogenation appears to be occurring in the higher concentration portion of the plume slightly downgradient from the base boundary. It is possible that some portions of the plume are aerobic and exhibit Type 3 behavior. The availability of DO, redox potential, and other important geochemical indicators would be clarified by the sampling of protocol parameters. The general lack of VC may indicate that DCE is not biodegrading, or is degrading aerobically. It is also possible, however, that some DCE is reductively dehalogenated to VC, but that VC is not detected because of rapid aerobic biodegradation or volatilization in this near-surface environment.

The effects of these fate and transport processes on the dissolved CAH groundwater plume could be investigated using analytical methods and/or numerical solute-transport modeling. Because the plume appears to be stable, mass loss within the plume from biodegradation, discharge, evapotranspiration, etc., are more important mechanisms than advective contaminant transport, dilution, and dispersion. Therefore, modeling efforts would focus on developing a total water budget and mass budget for the plume. The mass loss from the horizontal drains and/or groundwater extraction would be factored into this analysis. Data collection and analytical requirements are discussed in Section 3.

SECTION 3

COLLECTION OF ADDITIONAL DATA

To complete a demonstration and to document that RNA of chlorinated solvents is viable at OU 4, some additional site-specific physical and chemical hydrogeologic data are needed to supplement the available site data. Many of the necessary measurements and analyses (listed below) have been performed during the site characterizations at OU 4; however, gaps in the available data do exist. In addition, some of the data are to be collected specifically to assess the potential for use of RNA as viable remedial alternative.

Physical hydrogeologic characteristics required to fully evaluate RNA at OU 4 include:

- Depth to the groundwater in site monitoring wells, and screened intervals;
- Locations and screened intervals of downgradient domestic wells and their uses;
- Locations of receptor exposure points and potential for impact;
- Locations and rates of groundwater recharge and discharge;
- Locations and rates of evapotranspiration and volatilization;
- Areas of constant hydraulic head (for modeling);
- Horizontal and vertical hydraulic gradients and the distribution of hydraulic head;
- Aquifer saturated thickness and physical boundaries;
- Hydraulic conductivity as determined through slug tests and downhole flow meter tests;
- Identification of preferential migration pathways and estimates of migration rates;
- Estimates of dispersivity, where possible;
- Stratigraphic and geochemical analysis of subsurface media; and
- Groundwater temperature.

Chemical hydrogeologic characteristics to be determined include:

- DO concentrations;
- Specific conductance;
- pH;
- Redox potential;
- Carbon dioxide concentrations;
- Total organic carbon (TOC) and, if possible, forms of carbon; and
- Additional chemical analysis of water and soil samples for the parameters listed in Table 3.1.

These physical and chemical hydrogeological parameters are measured to further refine the site conceptual model of RNA and to aid in developing and calibrating the groundwater flow portion of a site-specific solute transport model (if used). In addition to the listed physical and chemical data, biological data may be collected through microcosm studies. These data can provide direct evidence of the occurrence of intrinsic bioremediation if properly designed and interpreted. Microcosms are discussed in Subsection 3.6.

There are gaps in chemical and physical data that preclude a more thorough understanding of RNA at OU 4. Temporal, spatial, and analytical gaps in the available groundwater chemical data would be clarified by additional sampling for the parameters listed in Table 3.1 and Appendix E. Parsons ES recommends sampling many of the existing monitoring points to gain a better understanding of the active biodegradation processes, prior to intrusive work (soil sampling, microcosms, monitoring points, etc.) at the site. Most existing off-base monitoring wells should be sampled (Figure 2.8). In addition, the on-base monitoring wells along sections A-A', B-B', and C-C' and background wells upgradient of Landfill's 1 and 2 should be sampled (Figures 1.2, 2.9, 2.10, 2.11). All monitored seeps, and other potential seeps that previously have not been identified, should be sampled. Additional monitoring points could be sampled at the discretion of Hill AFB. For this additional sampling, it is important that DO and redox potential are measured. It also is important that the 1,2-DCE analyses are separated into the individual isomers (*cis* and *trans*) and that analytical detection limits are sufficiently low to confirm the presence of these compounds and other TCE degradation products.

TABLE 3.1
ANALYTICAL PROTOCOL FOR
GROUNDWATER AND SOIL SAMPLES
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MATRIX Analyte	METHOD	FIELD (F) OR FIXED-BASE LABORATORY (L)
WATER		
Total Iron	Colorimetric, Hach Method 8008	F
Ferrous Iron (Fe ²⁺)	Colorimetric, Hach Method 8146	F
Ferric Iron (Fe ³⁺)	Difference between total and ferrous iron	F
Manganese	Colorimetric, Hach Method 8034	F
Sulfate	Colorimetric, Hach Method 8051	F
Nitrate	Titrimetric, Hach Method 8039	F
Nitrite	Titrimetric, Hach Method 8507	F
ORP	A2580B, direct-reading meter	F
Oxygen	Direct-reading meter	F
pH	USEPA method E150.1/SW9040, direct-reading meter	F
Conductivity	USEPA method E120.1/SW9050, direct-reading meter	F
Temperature	USEPA method E170.1, direct-reading meter	F
Carbon Dioxide	Titrimetric, Hach Method 1436-01	F
Alkalinity (Carbonate [CO ₃ ²⁻] and Bicarbonate [HCO ₃ ⁻])	F = Titrimetric, Hach Method 8221 L = USEPA Method 310.1	L
Nitrate + Nitrite	USEPA Method 353.1	L
Chloride	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
Methane, Ethane, Ethene	RSKSOP-147 ^u	L
Dissolved Organic Carbon	RSKSOP-102	L
VOCs (BTEX, CAHs, chloroform, chloromethane)	RSKSOP-148	L
SOIL		
Total Organic Carbon	RSKSOP-102 & RSKSOP-120	L
Moisture	ASTM D-2216	L
VOCs (BTEX + CAHs)	RSKSOP-124, modified	L

RSKSOP = Robert S. Kerr Laboratory (now NRMRL); see Appendix E for corresponding EPA methods.

Note: Additional analyses (as indicated in Appendix E) also may be performed.

Concentration contour (isopleth) maps and/or downgradient profiles of these data will facilitate a more thorough evaluation of the biodegradation processes in effect. The spatial and vertical variation of groundwater flow velocity should be measured with flow meters to better evaluate heterogeneity at the site.

In general, thorough and complete physical, chemical, and biological data will allow a determination of which biodegradation processes are active, and will provide information necessary for meaningful and accurate fate and transport modeling. Inorganic groundwater chemical parameters [e.g., DO, nitrate, iron, sulfate, and chloride] are measured to evaluate active biodegradation via the pathways discussed in Subsection 2.2.2. Concentrations of DO are indicative of aerobic versus anaerobic conditions. Nitrate and sulfate decreases (reduction to nitrite and sulfide) in the plume relative to the non-contaminated areas may be indicative of reductive dehalogenation. Ferrous Iron also is a result of reducing environmental conditions. Chloride ion increases in the plume relative to the non-contaminated areas may indicate de-chlorination by anaerobic and aerobic biological processes. Elevated carbon dioxide relative to background may indicate complete mineralization of CAHs, as it is the innocuous by-product of the biodegradation pathways. However, carbon dioxide also is abundantly produced by soil zone and geochemical processes. Redox potential is measured to help evaluate the potential for reductive dehalogenation, and is an indicator parameter during well purging (along with DO, temperature, pH, and conductivity). Chloromethane, methane, ethane, and ethene are measured for evidence of complete dehalogenation of CAHs. Chloromethane may be indicative of the aerobic biodegradation of VC and the anaerobic biodegradation of DCA. Ethane and ethene are by-products of anaerobic reductive dehalogenation. Relative concentrations and changes in the concentrations of these VOCs also can be used to further evaluate the ongoing processes, as discussed in Subsection 2.2.2. Soil analyses are largely performed to evaluate the distribution and concentrations of organic carbon and for soil microcosms. Additional chemical analyses not listed in Table 3.1 or geotechnical analyses may be performed at discretion. Additional analytes that may be tested are listed in Appendix E.

To obtain these data, soil and groundwater samples are collected and analyzed. The following sections describe the procedures to be followed when collecting additional site-specific data. Section 3.1 and Section 3.2 describe procedures for intrusive investigation. However, additional intrusive work at OU 4 is not recommended until further groundwater analytical data to characterize the active biological processes are evaluated. Additional intrusive investigation may be recommended after analysis of the additional sampling of existing monitoring points for the specific parameters listed in Table 3.1. Procedures to collect soil core samples are described in Section 3.1. Procedures for the

installation of new monitoring points are described in Section 3.2. Procedures to collect groundwater grab samples and to sample groundwater monitoring wells, surface water, and newly installed groundwater monitoring points are described in Section 3.3. Sample handling procedures are described in Section 3.4, and procedures to measure aquifer parameters (e.g., hydraulic conductivity) are described in Section 3.5. CAH-degradation microcosm studies are discussed in Section 3.6.

3.1 SOIL SAMPLING AND ANALYSIS

The following sections describe soil sampling locations, sample collection techniques, equipment decontamination procedures, site restoration, and management of investigation-derived waste materials.

3.1.1 Soil Sampling Locations and Analyses

Additional soil sampling is not proposed until additional groundwater sampling is performed. In the event that soil samples are eventually collected, a minimum of two samples will be obtained from each location. One sample will be obtained at the water table, and one will be obtained beneath the water table. Additional samples and sampling intervals may be selected at the discretion of the field scientist. Soil samples should be collected above the water table for analysis of VOCs where soil sources of groundwater contamination are suspected. However, the main purpose of soil sampling will be to determine aquifer matrix TOC concentrations and to collect cores for microcosms. If possible, at least two saturated soil samples from locations upgradient, crossgradient, or far downgradient from the contaminant source will be analyzed for these two parameters. Soil microcosm results from another Hill AFB OU may be applicable to OU 4, and therefore, may not be necessary.

A portion of each sample will be used to measure soil headspace, while another portion of selected samples will be sent to the laboratory for analytical analysis. Each laboratory soil sample will be placed in an analyte-appropriate sample container and hand-delivered to the field laboratory personnel for analysis. Each headspace screening sample will be placed in a sealed plastic bag or mason jar and allowed to sit for at least 5 minutes. Soil headspace will then be determined using an organic vapor meter (OVM), and the results will be recorded in the field records by the field scientist.

3.1.2 Sample Collection Using the Geoprobe® System

Soil samples will be collected using a Geoprobe® system (or similar system), which is a hydraulically powered percussion/probing machine capable of advancing sampling

tools through unconsolidated soils. This system allows rapid collection of soil, soil gas, or groundwater samples at shallow depths while minimizing the generation of investigation-derived waste materials. Figure 3.1 shows a diagram of the Geoprobe® system.

Soil samples will be collected using a probe-drive sampler. The probe-drive sampler serves as both the driving point and the sample collection device and is attached to the leading end of the probe rods. To collect a soil sample, the sampler is pushed or driven to the desired sampling depth, the drive point is retracted to open the sampling barrel, and the sampler is subsequently pushed into the undisturbed soils. The soil cores are retained within brass, stainless steel, or clear acetate liners inside the sampling barrel. The probe rods are then retracted, bringing the sampling device to the surface. The soil sample can then be extruded from the liners for lithologic logging, or the liners can be cut to the desired length, capped, and submitted to the analytical laboratory for testing of the undisturbed samples.

If the probe-drive sampling technique described above is inappropriate, inadequate, or unable to efficiently provide sufficient soil samples for the characterization of the site, continuous soil samples will be obtained from conventional soil boreholes using a hand auger or similar method judged acceptable by the field scientist. Procedures will be modified, if necessary, to ensure good sample recovery.

The field scientist will be responsible for observing all field investigation activities, maintaining a detailed descriptive log of all subsurface materials recovered during soil coring, photographing representative samples, and properly labeling and storing samples. An example geologic boring log form is presented as Figure 3.2. The descriptive log will contain:

- Sample interval (top and bottom depth);
- Sample recovery;
- Presence or absence of contamination (as indicated by OVM readings);
- Lithologic description, including relative density, color, major textural constituents, minor constituents, porosity, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, relative permeability, and any other significant observations; and
- Depths of lithologic contacts and/or significant textural changes measured and recorded to the nearest 0.1 foot.

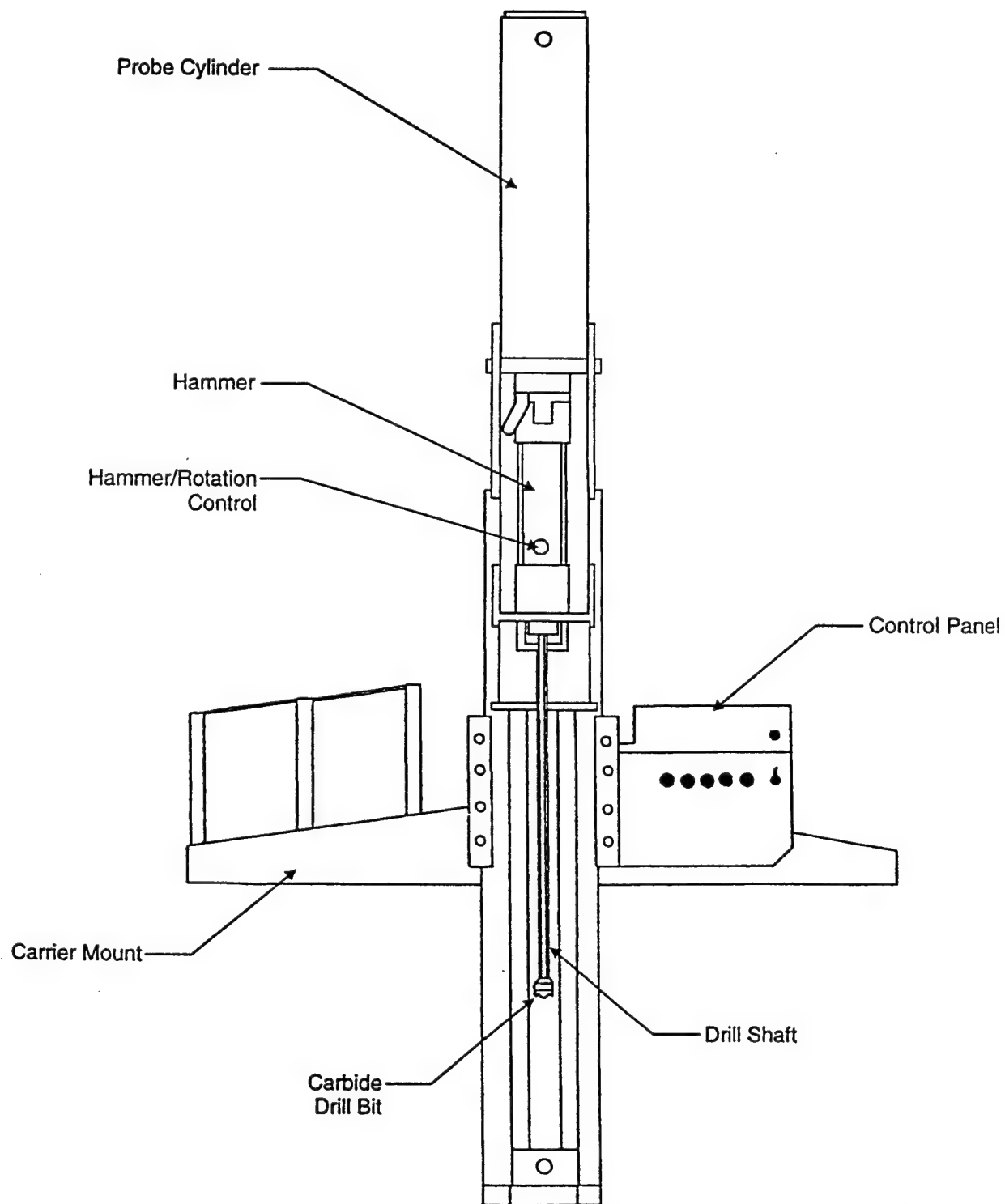


FIGURE 3.1

**CROSS-SECTION
OF GEOPROBE®**

Hill Air Force Base, Utah

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GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.: _____ CONTRACTOR: _____ DATE SPUD: _____
 CLIENT: AFCEE RIG TYPE: _____ DATE CMPL: _____
 JOB NO.: 729080 DRLG METHOD: _____ ELEVATION: _____
 LOCATION: HILL, AFB BORING DIA.: _____ TEMP: _____
 GEOLOGIST: _____ DRLG FLUID: _____ WEATHER: _____
 COMENTS: _____

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample		Penet Res	PD(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
					No.	Depth (ft)					
	1										
	5										
	10										
	15										
	20										
	25										
	30										
	35										

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

▼ Water level drilled

FIGURE 3.2

GEOLOGIC BORING LOG

Hill Air Force Base, Utah

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Base personnel will be responsible for identifying the location of all utility lines, fuel lines, or any other underground infrastructure prior to potential intrusive sampling activities. All necessary digging permits will be obtained through Base personnel prior to mobilizing to the field. If necessary, Base personnel also will be responsible for acquiring drilling and monitoring point installation permits for the proposed locations. The environmental consultant will provide trained operators for the Geoprobe®.

3.1.3 Datum Survey

The horizontal location of all soil sampling locations relative to established site coordinates will be measured by a surveyor. Horizontal coordinates will be measured to the nearest 0.1 foot. The elevation of the ground surface will also be measured to the nearest 0.1 foot relative to USGS msl data.

3.1.4 Site Restoration

After sampling is complete, each sampling location will be restored as closely to its original condition as possible. Holes created by the Geoprobe® in sandy soils similar to those found at the Base tend to cave in soon after extraction of the drive sampler. However, any test holes remaining open after extraction of the push rod will be sealed with bentonite chips, pellets, or grout to eliminate any creation or enhancement of contaminant migration pathways to the groundwater. Soil sampling using the Geoprobe® creates low volumes of soil waste. Soil not used for sampling will be placed in 55-gallon drums to await proper disposal by Base personnel. Alternate methods of soil waste disposal will be considered by the field scientist as recommended by Base personnel.

3.1.5 Equipment Decontamination Procedures

Prior to arriving at the site, and between each sampling location, probe rods, tips, sleeves, pushrods, samplers, tools, and other downhole equipment will be decontaminated using a high-pressure, steam/hot water wash. Only potable water will be used for decontamination.

Between each soil sample, the sampling barrel will be disassembled and decontaminated with Alconox® and potable water. The barrel will then be rinsed with deionized water and reassembled with new liners. Between uses, the sampling barrel will be wrapped in clean plastic or foil to prevent contamination.

All rinseate will be collected for transportation and proper disposal by Base personnel. Alternate methods of rinseate disposal will be considered by the field scientist as recommended by Base personnel.

Potable water to be used during equipment cleaning, decontamination, or grouting will be obtained from one of the Base potable water supplies. Water use approval will be verified by contacting the appropriate facility personnel. The field scientist will make the final determination as to the suitability of site water for these activities. Precautions will be taken to minimize any impact to the surrounding area that might result from decontamination operations.

3.2 MONITORING POINT INSTALLATION

As with the soil sampling, additional groundwater monitoring points are not proposed until additional groundwater sampling is performed. In the event that monitoring points are eventually installed at OU 4 to support a demonstration of RNA, the monitoring points could be installed according to the following protocol. The following sections describe monitoring point installation, completion intervals, development, and equipment decontamination procedures. If site conditions prevent installation of monitoring points, groundwater grab samples will be collected using the Geoprobe[®] apparatus.

3.2.1 Monitoring Point Locations and Completion Intervals

Monitoring point locations will be selected to provide the data necessary for successful implementation of a site-specific contaminant fate and transport model, to monitor potential chlorinated solvent migration, and to evaluate the active processes of RNA and associated contaminant mass loss.

All monitoring points installed for this evaluation will be installed in the shallow groundwater system. Monitoring points may be installed singly, or in clusters of up to three points. Single monitoring points will be screened near the top of the saturated zone. All shallow monitoring points will have a 3-foot screened interval, while deeper points will have 6-inch screens. Monitoring point clusters will include one point that is screened at the top of the saturated zone and other points that will be screened at depths based on hydrogeologic conditions. The screened intervals of 3 feet for shallow monitoring points and 6 inches for deep monitoring points will help mitigate the dilution of water samples from potential mixing of contaminated and uncontaminated groundwater in the monitoring point casing. Adjustments of the depths and lengths of the screened intervals of the monitoring points may be necessary in response to actual aquifer conditions and contaminant distribution identified during Geoprobe[®] testing.

3.2.2 Monitoring Point Installation Procedures

3.2.2.1 Pre-Placement Activities

All necessary digging, coring, and drilling permits will be obtained prior to field mobilization. In addition, all utility lines will be located, and proposed drilling locations will be cleared prior to any intrusive activities. Responsibilities for these permits and clearances are discussed in Section 3.1.2.

Water used in monitoring point installation and equipment cleaning will be obtained from one of the Base potable water supplies. Water use approval will be verified by contacting the appropriate facility personnel. The field scientist will make the final determination as to the suitability of site water for these activities.

3.2.2.2 Monitoring Point Materials Decontamination

Monitoring point installation and completion materials will be inspected by the field scientist and determined to be clean and acceptable prior to use. If not factory sealed, the well points, casing, and tubing will be cleaned prior to use with a high-pressure, steam/hot-water cleaner using approved water. Materials that cannot be cleaned to the satisfaction of the field scientist will not be used.

3.2.2.3 Installation and Materials

This section describes the procedures for installation of monitoring points. Monitoring points will be installed using either 0.375-inch Teflon[®] tubing connected to a 0.5-inch-diameter stainless steel screen or a 0.5-inch inside-diameter (ID)/0.75-inch outside-diameter (OD) polyvinyl chloride (PVC) screen and casing.

3.2.2.3.1 Deep Monitoring Points

The deep monitoring points will be installed in boreholes using the Geoprobe[®], or similar push-technology system. The deep monitoring points will be constructed of a sacrificial drive point attached to a length of 0.5-inch-diameter stainless steel mesh that will function as the well screen, which in turn will be connected to 0.375-inch Teflon[®] tubing.

To install the deep monitoring points, the borehole is punched and sampled to several feet above the target depth for the monitoring point. The probe rods are withdrawn from the borehole, and the soil sampler is replaced with the well point assembly. An appropriate length of Teflon[®] tubing is threaded through the probe rods and attached to the well point. The assembly is lowered into the borehole and then driven down to the

target depth and sampling zone. The probe rods are removed, leaving the sacrificial tip, screen assembly, and tubing behind. The soil is likely to cave in around the screen and tube assembly; where this does not occur, silica sand will be emplaced to create a sand pack around the well point, and the borehole annular space around the tubing above the sand pack will be filled with granular bentonite or grout to seal it. Monitoring point construction details will be noted on a Monitoring Point Installation Record form (Figure 3.3).

3.2.2.3.2 Shallow Monitoring Points

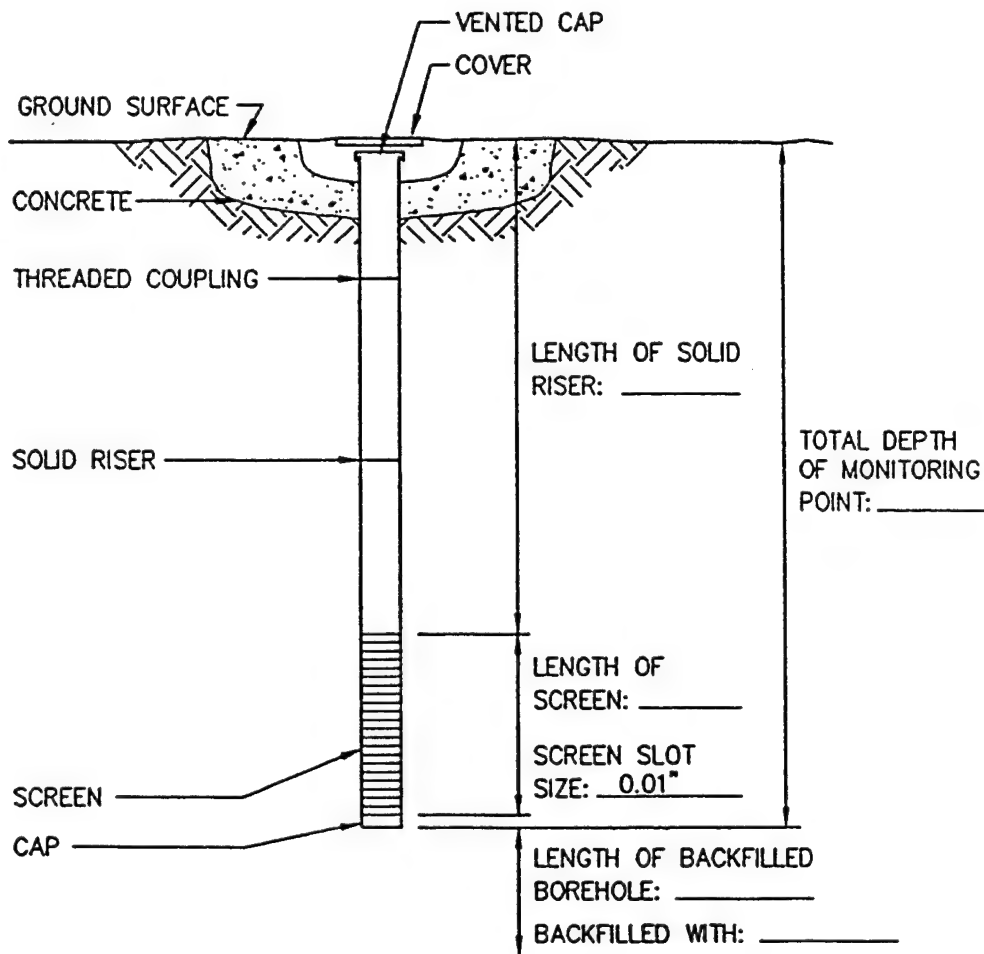
If subsurface conditions permit, shallow monitoring points will be constructed of 0.75-inch-OD/0.5-inch-ID PVC casing and well screen to provide additional water level information. Approximately 3 feet of factory-slotted screen will be installed for each shallow monitoring point. Shallow 0.5-inch-ID PVC monitoring points will be installed by punching and sampling a borehole with the Geoprobe[®]. Effective installation of the shallow monitoring points requires that the boreholes remain temporarily open after the borehole is punched and the rods are withdrawn. Upon removing the rods, the borehole depth will be measured to determine if the hole remains open. If the borehole is open, the 0.5-inch-ID PVC casing and screen will be placed at the appropriate depths. The annular space around the screen will be filled with sand filter pack, and the annulus around the casing will be filled with grout or bentonite. Monitoring point construction details will be noted on a Monitoring Point Installation Record form (Figure 3.3). This information will become part of the permanent field record for the site.

Monitoring point screens will be constructed of flush-threaded, Schedule 40 PVC with an ID of 0.5 inch. The screens will be factory slotted with 0.01-inch openings. Monitoring point screens will be placed to sample and provide water level information at or near the water table. Blank monitoring point casing will be constructed of Schedule 40 PVC with an ID of 0.5 inch. All monitoring point casing sections will be flush-threaded; joints will not be glued. The casing at each monitoring point will be fitted with a bottom cap and a top cap constructed of PVC.

If subsurface conditions do not permit the boreholes to stay open (i.e., if the formation collapses in the hole), monitoring points constructed of 0.375-inch Teflon[®] described in Section 3.2.2.3.1 will be installed. Should 0.5-inch-ID PVC shallow monitoring points not be installed, the only resulting data gap will be the lack of water level information for that particular location. The decision to install 0.5-inch-ID PVC monitoring points will be made in the field once the open-hole stability of subsurface soils and Geoprobe[®] equipment can be evaluated.

MONITORING POINT INSTALLATION RECORD

JOB NAME HILL AIR FORCE BASE MONITORING POINT NUMBER _____
 JOB NUMBER 729080 INSTALLATION DATE _____ LOCATION _____
 DATUM ELEVATION _____ GROUND SURFACE ELEVATION _____
 DATUM FOR WATER LEVEL MEASUREMENT _____
 SCREEN DIAMETER & MATERIAL _____ SLOT SIZE _____
 RISER DIAMETER & MATERIAL _____ BOREHOLE DIAMETER _____
 CONE PENETROMETER CONTRACTOR _____ ES REPRESENTATIVE _____



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET
 BELOW DATUM.

TOTAL MONITORING POINT DEPTH _____ FEET
 BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.3

MONITORING POINT INSTALLATION RECORD

Hill Air Force Base, Utah

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The field scientist will verify and record the total depth of the monitoring point, the lengths of all casing sections, and the depth to the top of all monitoring point completion materials. All lengths and depths will be measured to the nearest 0.1 foot.

3.2.2.4 Monitoring Point Completion or Abandonment

A number of the monitoring points will be completed above grade, and as needed, steel or PVC protective casing will be used to protect the well points from tampering and damage. The number of permanent monitoring points will be determined by the field scientist. The completion of the monitoring points will be similar to those protecting the existing monitoring wells unless otherwise specified by Base personnel.

Those monitoring points not completed with an external protective casing will be abandoned. The PVC casing and screen or Teflon[®] tubing will be extracted as far as possible and discarded. While holes created with the Geoprobe[®] in sandy soils similar to those found at the Base tend to cave in soon after extraction of the drive rod, any test holes remaining open after extraction of the casing will be sealed with bentonite chips, pellets, or grout to eliminate any creation or enhancement of contaminant migration pathways to the groundwater. After monitoring point completion or abandonment, each site will be restored as closely as possible to its original condition.

3.2.3 Monitoring Point Development and Records

The monitoring points will be developed prior to sampling to remove fine sediments from the portion of the formation adjacent to the well point screen. Development will be accomplished using a peristaltic pump. The pump will be inserted into or attached to the well point, and water will be removed until DO, pH, temperature, and specific conductivity stabilize. Monitoring point development will occur a minimum of 24 hours prior to sampling.

A development record will be maintained for each monitoring point. The development record will be completed in the field by the field scientist. Figure 3.4 is an example of a development record used for similar well installations. Development records will include:

- Monitoring point number;
- Date and time of development;
- Development method;

MONITORING POINT DEVELOPMENT RECORD

Job Number: _____ Job Name: Hill AFB
Location _____ By _____ Date _____
Well Number _____ Measurement Datum TOC

Pre-Development Information

Time (Start): _____

Water Level: _____

Total Depth of Well: _____

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature (°F °C) _____
Specific Conductance (µS/cm) _____

Interim Water Characteristics

Gallons Removed _____

pH _____

Temperature (°F °C) _____

Specific Conductance (µS/cm) _____

Post-Development Information

Time (Finish): _____

Water Level: _____

Total Depth of Well: _____

Approximate Volume Removed: _____

Water Characteristics

Color _____ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material _____
pH _____ Temperature (°F °C) _____
Specific Conductance (µS/cm) _____

Comments: _____

FIGURE 3.4

MONITORING POINT DEVELOPMENT RECORD

Hill Air Force Base, Utah

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- Monitoring point depth;
- Volume of water produced;
- Description of water produced;
- Post-development water level and monitoring point depth; and
- Field analytical measurements, including pH and specific conductivity.

Development waters will be collected and held for proper disposal by Base personnel. Alternate methods of water disposal will be considered by the field scientist as recommended by Base personnel.

3.2.4 Monitoring Point Location and Datum Survey

The location and elevation of the well points will be surveyed soon after completion. Horizontal coordinates will be measured to the nearest 0.1 foot relative to established Base coordinates. The elevation of the ground surface adjacent to the protective casing will be measured relative to the USGS msl datum. The ground surface elevation will be measured to the nearest 0.1 foot. A top-of-casing datum will be measured to the nearest 0.01 foot for all monitoring points constructed of 0.5-inch PVC casing and well screen. Because water levels cannot be measured through the well point tubing, no datum elevation, such as top of casing, will be measured for monitoring points constructed with Teflon[®] tubing.

3.2.5 Water Level Measurements

Water levels at existing monitoring wells and 0.5-inch PVC monitoring points will be measured within a short time period so that the water level data are comparable. The depth to water below the measurement datum will be measured to the nearest 0.01 foot using an electric water level probe or an oil/water interface probe.

3.3 GROUNDWATER SAMPLING PROCEDURES

This section describes the scope of work required for collection of groundwater quality samples. Samples will be collected from site monitoring wells (e.g., previously installed wells), newly installed groundwater monitoring points, springs, and at any grab-sample locations. A peristaltic pump or bladder pump with dedicated high-density polyethylene (HDPE) tubing will be used to collect groundwater samples at all wells and monitoring points. A Grundfos[®] Redi-Flo II[®] pump may be used for monitoring well purging prior

to sampling. In order to maintain a high degree of QC during this sampling event, the procedures described in the following sections will be followed.

Sampling will be conducted by qualified scientists and technicians who are trained in proper sampling, documentation, and chain-of-custody procedures. In addition, sampling personnel will have thoroughly reviewed this work plan prior to sample acquisition and will have a copy of the work plan available onsite for reference. Groundwater sampling includes the following activities:

- Assembly and preparation of equipment and supplies;
- Inspection of the monitoring well/point integrity including:
 - Protective cover, cap, and lock,
 - External surface seal and pad,
 - Monitoring point stick-up, cap, and datum reference, and
 - Internal surface seal;
- Groundwater sampling, including:
 - Water level and product thickness measurements,
 - Visual inspection of sample water,
 - Monitoring point casing evacuation, and
 - Sample collection;
- Sample preservation and shipment, including:
 - Sample preparation,
 - Onsite measurement of physical parameters, and
 - Sample labeling;
- Completion of sampling records: and
- Sample disposition.

Detailed groundwater sampling and sample handling procedures are presented in following sections.

3.3.1 Preparation for Sampling

All equipment to be used for sampling will be assembled and properly cleaned and calibrated (if required) prior to arriving in the field. In addition, all record-keeping materials will be gathered prior to leaving the office.

3.3.1.1 Equipment Cleaning

All portions of sampling and test equipment that will contact the sample matrix will be thoroughly cleaned before each use. This includes the Geoprobe® sampling tools, sampling pumps, nondisposable bailers, water level probe and cable, test equipment for onsite use, and other equipment or portions thereof that will contact the samples. Given the types of sample analyses to be conducted, the following cleaning protocol will be used:

- Wash with potable water and phosphate-free laboratory detergent (HP-II detergent solutions, as appropriate);
- Rinse with potable water;
- Rinse with isopropyl alcohol;
- Rinse with distilled or deionized water; and
- Air dry.

Any deviations from these procedures will be documented in the field scientist's field notebook and on the groundwater sampling record (Figure 3.5).

If precleaned, disposable sampling equipment is used, the cleaning protocol specified above will not be required. Laboratory-supplied sample containers will be cleaned and sealed by the laboratory. The type of container provided and the method of container decontamination will be documented in the USEPA mobile laboratory's permanent record of the sampling event.

3.3.1.2 Equipment Calibration

As required, field analytical equipment will be calibrated according to the manufacturers' specifications prior to field use. This applies to equipment used for onsite measurements of DO, pH, electrical conductivity, temperature, redox potential, sulfate, nitrate, ferrous iron (Fe^{2+}), and other field parameters listed on Table 3.1.

3.3.2 Well and Monitoring Point Sampling Procedures

Special care will be taken to prevent contamination of the groundwater and extracted samples. The two primary ways in which sample contamination can occur are through contact with improperly cleaned equipment and through cross-contamination due to insufficient cleaning of equipment between wells and monitoring points. To prevent such contamination, the water level probe and cable used to determine static water levels and total well depths will be thoroughly cleaned before and after field use and between uses at different sampling locations according to the procedures presented in Section 3.3.1.1.

Sampling Location Hill AFB
Sampling Dates _____

GROUND WATER SAMPLING RECORD - MONITORING WELL _____ (number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;
DATE AND TIME OF SAMPLING: _____, 1996 _____ a.m./p.m.
SAMPLE COLLECTED BY: MV/BB of Parsons ES
WEATHER: _____

DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOP OF WELL CASING

MONITORING WELL CONDITION:

☐ LOCKED: _____ ☐ UNLOCKED

WELL NUMBER (IS - IS NOT) APPARENT _____

STEEL CASING CONDITION IS: _____

INNER PVC CASING CONDITION IS: _____

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT _____

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 ☐ EQUIPMENT CLEANED BEFORE USE WITH ALCONOX, ISOPROPYL ALCOHOL, AND dH₂O
Items Cleaned (List): _____

2 ☐ PRODUCT DEPTH _____ FT. BELOW DATUM
Measured with: _____

WATER DEPTH _____ FT. BELOW DATUM
Measured with: _____

3 ☐ WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: _____
Odor: _____
Other Comments: _____

4 ☐ WELL EVACUATION:
Method: _____
Volume Removed: _____
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: _____
Other comments: _____

FIGURE 3.5

**GROUNDWATER
SAMPLING RECORD**

Hill Air Force Base, Utah

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Dedicated tubing will be used at each well or monitoring point developed, purged, and/or sampled with the sampling pump. Pumps and nondisposable bailers will be decontaminated according to procedures listed in Section 3.3.1.1. In addition to the use of properly cleaned equipment, a clean pair of new, disposable nitrile or latex gloves will be worn by the sampling personnel each time a different well or monitoring point is sampled.

The following paragraphs present the procedures to be followed for groundwater sample collection from groundwater monitoring wells and monitoring points. These activities will be performed in the order presented below. Exceptions to this procedure will be noted in the field scientist's field notebook or on the groundwater sampling record.

3.3.2.1 Preparation of Location

Prior to starting the sampling procedure, the area around the existing wells and new monitoring points will be cleared of foreign materials, such as brush, rocks, and debris. These procedures will prevent sampling equipment from inadvertently contacting debris around the monitoring well/point.

3.3.2.2 Water Level and Total Depth Measurements

Prior to removing water from the monitoring well or PVC-cased monitoring point, the static water level will be measured. An electric water level probe or oil/water interface probe will be used to measure the depth to groundwater below the datum to the nearest 0.01 foot. After measuring the static water level, the water level probe will be slowly lowered to the bottom of the monitoring well/point, and the depth will be measured to the nearest 0.01 foot. Based on these measurements, the volume of water to be purged from the monitoring well/point will be calculated.

3.3.2.3 Monitoring Well/Point Purging

The volume of water contained within the monitoring well/point casing at the time of sampling will be calculated, and at least three times the calculated volume will be removed from the well/point. A peristaltic pump will be used for monitoring well and monitoring point purging, depth and volume permitting, and a Grundfos Redi-Flo II® pump, Waterra® inertial pump, or bailer will be used to purge all monitoring wells or points in which a peristaltic pump cannot be used. All purge waters will be collected for proper disposal by the Base.

If a monitoring well/point is evacuated to a dry state during purging, the monitoring well/point will be allowed to recharge, and the sample will be collected as soon as sufficient water is present in the monitoring well/point to obtain the necessary sample quantity. Sample compositing or sampling over a lengthy period by accumulating small volumes of water at different times to obtain a sample of sufficient volume will not be allowed.

3.3.2.4 Sample Extraction

Dedicated HDPE tubing and a peristaltic pump will be used to extract groundwater samples from monitoring wells/points whenever depth to groundwater permits; otherwise, a bladder pump, a Waterra[®] inertial pump, or a bailer will be used. The tubing, pump, or bailer will be lowered through the casing into the water gently to prevent splashing. The sample will be transferred directly into the appropriate sample container. The water will be carefully poured down the inner walls of the sample bottle to minimize aeration of the sample.

Unless other instructions are given by the mobile laboratory, sample containers will be completely filled so that no air space remains in the container. Excess water collected during sampling will be disposed of in the same manner as purge water.

3.3.2.5 Grab Sampling

In the event monitoring points are not installed, groundwater grab samples will be collected using the Geoprobe[®] apparatus. To collect these samples, a properly decontaminated, screened probe tip will be driven to the desired sampling depth. As it is driven to depth, the screen will be protected inside the probe rods. After reaching the desired depth, the outer rods will be withdrawn to expose the screen. Purging and sampling procedures will be identical to those for monitoring points. After sampling, the rods and screen will be withdrawn, and the holes will be abandoned as described in Sections 3.1.4 and 3.2.2.4.

3.3.3 Groundwater Sampling at Springs

To determine if CAHs are discharging to the ground surface (and hence creating additional receptor exposure pathways), groundwater emanating from springs, seeps, or other surface water in the study area also will be sampled. Sampling procedures will depend on the manner in which the groundwater discharges to the surface. If possible, sample bottles will be held directly under the discharge area. If a pool of water is present,

water will be collected from the bottom of the pool using clean sample jars that will be unscrewed underwater. As needed, a jar will be used to transfer water to preserved sample containers.

3.3.4 Onsite Groundwater Parameter Measurement

As indicated on Table 3.1, many of the groundwater chemical parameters will be measured onsite. Some of the measurements will be made with direct-reading meters, while others will be made using a Hach[®] portable colorimeter in accordance with specific Hach[®] analytical procedures. These procedures are described in the following subsections.

All glassware or plasticware used in the analyses will have been cleaned prior to sample collection by thoroughly washing with a solution of laboratory-grade, phosphate-free detergent (e.g., Alconox[®]) and water, and rinsing with isopropyl alcohol and deionized water to prevent interference or cross-contamination between measurements. If concentrations of an analyte are above the range detectable by the titrimetric or colorimetric methods, the analysis will be repeated by diluting the groundwater sample with distilled water until the analyte concentration falls to a level within the range of the method. All rinseate and sample reagents accumulated during groundwater analysis will be collected in glass containers fitted with screw caps. These waste containers will be clearly labeled as to their contents and carefully stored for proper disposal.

3.3.4.1 Dissolved Oxygen Measurements

DO measurements will be made using a meter with a downhole oxygen sensor or a sensor in a flow-through cell before and immediately following groundwater sample acquisition. When DO measurements are taken in monitoring wells/points that have not yet been sampled, the existing monitoring wells/points will be purged until DO levels stabilize. The lowest stable DO reading will be recorded.

3.3.4.2 pH, Temperature, and Specific Conductance

Because the pH, temperature, and specific conductance of a groundwater sample can change significantly within a short time following sample acquisition, these parameters will be measured in the field in unfiltered, unpreserved, "fresh" water collected using the same technique as the samples taken for laboratory analyses. The measurements will be made in a flow-through cell or a clean glass container separate from those intended for laboratory analysis, and the measured values will be recorded in the groundwater sampling record (Figure 3.5).

3.3.4.3 Oxidation/Reduction Potential

The redox potential of groundwater is an indication of the relative tendency of a solution to accept or transfer electrons. Redox reactions in groundwater are usually biologically mediated; therefore, the redox potential of a groundwater system depends upon and influences rates of biodegradation. Redox potential can be used to provide real-time data on the location of the contaminant plume, especially in areas undergoing anaerobic biodegradation. The redox potential of a groundwater sample taken inside the contaminant plume should be somewhat less than that taken in the upgradient location.

The redox potential of a groundwater sample can change significantly within a short time following sample acquisition and exposure to atmospheric oxygen. As a result, this parameter will be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for laboratory analyses. The measurements will be made as quickly as possible in a clean glass container separate from those intended for laboratory analysis or in a flow-through cell.

3.3.4.4 Alkalinity Measurements

Alkalinity in groundwater helps buffer the groundwater system against acids generated through both aerobic and anaerobic biodegradation processes. Alkalinity of the groundwater sample will be measured in the field by experienced field personnel via titrimetric analysis using USEPA-approved Hach® Method 8221 (0 to 5,000 mg/L as calcium carbonate) or a similar method. Alkalinity of the groundwater sample will also be measured in the laboratory using USEPA Method 310.1.

3.3.4.5 Nitrate- and Nitrite-Nitrogen Measurements

Nitrate-nitrogen concentrations are of interest because nitrate can act as an electron acceptor during biodegradation under anaerobic soil or groundwater conditions. Nitrate-nitrogen is also a potential nitrogen source for biomass formation for hydrocarbon-degrading bacteria. Nitrite-nitrogen is an intermediate byproduct in both ammonia nitrification and nitrate reduction in anaerobic environments.

Nitrate- and nitrite-nitrogen concentrations in groundwater will be measured in the field by experienced field personnel via colorimetric analysis using a Hach® DR/700 Portable Colorimeter. Nitrate concentrations in groundwater samples will be analyzed after preparation with Hach® Method 8039 (0 to 30.0 mg/L NO_3). Nitrite concentrations in groundwater samples will be analyzed after preparation with USEPA-approved Hach® Method 8507 (0 to 0.35 mg/L NO_2) or a similar method. Alternatively, samples may be submitted for laboratory analysis using USEPA Method 353.1 or its equivalent.

3.3.4.6 Sulfate and Sulfide Measurements

Sulfate in groundwater is a potential electron acceptor for biodegradation in anaerobic environments, and sulfide is resultant after sulfate reduction. The field scientist will measure sulfate and sulfide concentrations via colorimetric analysis with a Hach® DR/700 Portable Colorimeter after appropriate sample preparation. USEPA-approved Hach® Methods 8051 (0 to 70.0 mg/L SO_4) or and 8131 (0.60 mg/L S^{2-}) will be used to prepare samples and analyze sulfate and sulfide concentrations, respectively. Samples may also be submitted for laboratory analysis using a method such as Waters Capillary Electrophoresis Method N-601 or an equivalent.

3.3.4.7 Total Iron, Ferrous Iron, and Ferric Iron Measurements

Iron is an important trace nutrient for bacterial growth, and different states of iron can affect the redox potential of the groundwater and act as an electron acceptor for biological metabolism under anaerobic conditions. Iron concentrations will be measured in the field via colorimetric analysis with a Hach® DR/700 Portable Colorimeter after appropriate sample preparation. Hach® Method 8008 (or similar) for total soluble iron (0 to 3.0 mg/L $\text{Fe}^{3+} + \text{Fe}^{2+}$) and Hach® Method 8146 (or similar) for ferrous iron (0 to 3.0 mg/L Fe^{2+}) will be used to prepare and quantitate the samples. Ferric iron will be quantitated by subtracting ferrous iron levels from total iron levels.

3.3.4.8 Manganese Measurements

Manganese is a potential electron acceptor under anaerobic environments. Manganese concentrations will be quantitated in the field using colorimetric analysis with a Hach® DR/700 Portable Colorimeter. USEPA-approved Hach® Method 8034 (0 to 20.0 mg/L Mn) or similar will be used for quantitation of manganese concentrations. Sample preparation and disposal procedures are outlined earlier in Section 3.3.3.

3.3.4.9 Carbon Dioxide Measurements

Carbon dioxide concentrations are of interest because carbon dioxide is a byproduct of all biodegradation reactions. In addition, carbon dioxide in groundwater is a potential electron acceptor for methanogenic biodegradation under anaerobic conditions. Carbon dioxide concentrations in groundwater will be measured in the field via titrimetric analysis using Hach® Method 1436-01 (0 to 250 mg/L as CO_2). Sample preparation and disposal procedures are the same as outlined at the beginning of Section 3.3.3.

3.4 SAMPLE HANDLING FOR LABORATORY ANALYSIS

This section describes the handling of samples from the time of sampling until the samples are delivered to fixed-based laboratory. These procedures are premised on the USEPA NRMRL providing the field and fixed-base laboratory analytical services and would necessarily be modified as required if other services are contracted by Hill AFB.

3.4.1 Sample Preservation

The laboratory support personnel will add any necessary chemical preservatives prior to filling the sample containers. Samples will be prepared for transportation to the analytical laboratory by placing the samples in a cooler containing ice to maintain a shipping temperature of as close to 4 degrees centigrade (°C) as possible. Samples will be delivered promptly to the field laboratory personnel, who will be responsible for shipment of appropriate samples to the NRMRL in Ada, Oklahoma for analysis.

3.4.2 Sample Container and Labels

Sample containers and appropriate container lids will be provided by the field laboratory (see Appendix E). The sample containers will be filled as described in Sections 3.1.2 and 3.3.2.4, and the container lids will be tightly closed. The sample label will be firmly attached to the container side, and the following information will be legibly and indelibly written on the label:

- Facility name;
- Sample identification;
- Sample type (e.g., groundwater, soil);
- Sampling date;
- Sampling time;
- Preservatives added;
- Sample collector's initials; and
- Analyses requested.

3.4.3 Sample Shipment

After the samples are sealed and labeled, they will be packaged for transport to the onsite field laboratory. The packaged samples will be delivered by hand to the field laboratory. Delivery will occur as soon as possible after sample acquisition.

The following packaging and labeling procedures will be followed:

- Package sample so that it will not leak, spill, or vaporize from its container;
- Cushion samples to avoid breakage; and
- Add ice to container to keep samples cool.

USEPA personnel will be responsible for repackaging and overnight shipment of samples to the NRMRL in Ada, Oklahoma.

3.4.4 Chain-of-Custody Control

Chain-of-custody documentation for the shipment of samples from the field laboratory to the NRMRL analytical laboratory in Ada, Oklahoma, will be the responsibility of the USEPA field laboratory personnel.

3.4.5 Sampling Records

In order to provide complete documentation of the sampling event, detailed records will be maintained by the field scientist. At a minimum, these records will include the following information:

- Sample location (facility name);
- Sample identification;
- Sample location map or detailed sketch;
- Date and time of sampling;
- Sampling method;
- Field observations of
 - Sample appearance, and
 - Sample odor;
- Weather conditions;
- Water level prior to purging (groundwater samples, only);
- Total monitoring well/point depth (groundwater samples, only);
- Sample depth (soil samples, only);
- Purge volume (groundwater samples, only);
- Water level after purging (groundwater samples, only);
- Monitoring well/point condition (groundwater samples, only);
- Sampler's identification;

- Field measurements of pH, temperature, DO, and specific conductivity (groundwater samples, only); and
- Any other relevant information.

Groundwater sampling information will be recorded on a groundwater sampling form. Figure 3.5 shows an example of the groundwater sampling record. Soil sampling information will be recorded in the field log book.

3.4.6 Laboratory Analyses

Laboratory analyses will be performed on all groundwater and soil samples as well as the QA/QC samples described in Section 4. The analytical methods for this sampling event are listed in Table 3.1. Prior to sampling, USEPA NRMRL personnel will provide a sufficient number of analyte-appropriate sample containers for the samples to be collected. All containers, preservatives, and shipping requirements will be consistent with USEPA protocol or those listed in Appendix E of this plan.

USEPA laboratory support personnel will specify the necessary QC samples and prepare appropriate QC sample containers. For samples requiring chemical preservation, preservatives will be added to containers by the laboratory or USEPA NRMRL field personnel. Containers, ice chests with adequate padding, and cooling media will be provided by USEPA NRMRL laboratory personnel. Sampling personnel will fill the sample containers and return the samples to the field laboratory.

3.5 AQUIFER TESTING

3.5.1 Slug Tests

Slug tests may be conducted on selected previously installed 2-inch-ID monitoring wells to estimate the hydraulic conductivity of unconsolidated deposits at the site. This information is required to accurately estimate the velocity of groundwater and contaminants in the shallow saturated zone. A slug test is a single-well hydraulic test used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug tests can be used for both confined and unconfined aquifers that have a transmissivity of less than 7,000 square feet per day (ft^2/day). Slug testing can be performed using either a rising head or a falling head test. At this site, rising head and falling head methods will be used in sequence.

3.5.1.1 Definitions

- **Hydraulic Conductivity (K).** A quantitative measure of the ability of porous material to transmit water; defined as the volume of water that will flow through a unit cross-sectional area of porous or fractured material per unit time under a unit hydraulic gradient.
- **Transmissivity (T).** A quantitative measure of the ability of an aquifer to transmit water. It is the product of the hydraulic conductivity and the saturated thickness.
- **Slug Test.** Two types of testing are possible: rising head and falling head tests. A slug test consists of adding a slug of water or a solid cylinder of known volume to the well to be tested or removing a known volume of water or cylinder and measuring the rate of recovery of water level inside the well. The slug of a known volume acts to raise or lower the water level in the well.
- **Rising Head Test.** A test used in an individual well within the saturated zone to estimate the hydraulic conductivity of the surrounding formation by lowering the water level in the well and measuring the rate of recovery of the water level. The water level may be lowered by pumping, bailing, or removing a submerged slug from the well.
- **Falling Head Test.** A test used in an individual well to estimate the hydraulic conductivity of the surrounding formation by raising the water level in the well by insertion of a slug or quantity of water, and then measuring the rate of drop in the water level.

3.5.1.2 Equipment

The following equipment will be used to conduct a slug test:

- Teflon[®], PVC, or metal slugs;
- Nylon or polypropylene rope;
- Electric water level indicator;
- Pressure transducer/sensor;
- Field logbook/forms; and
- Automatic data-recording instrument (such as the Hermit Environmental Data Logger[®], In-Situ, Inc. Model SE1000B, or equivalent).

3.5.1.3 General Test Methods

Slug tests are accomplished by either removing a slug or quantity of water (rising head) or introducing a slug (falling head), and then allowing the water level to stabilize while taking water level measurements at closely spaced time intervals.

Because hydraulic testing will be completed on existing wells, it will be assumed that the wells were properly developed and that water levels have stabilized. Slug testing will proceed only after multiple water level measurements over time show that static water levels are in equilibrium. During the slug test, the water level change should be influenced only by the introduction (or removal) of the slug volume. Other factors, such as inadequate well development or extended pumping may lead to inaccurate results; in addition, slug tests will not be performed on wells with LNAPL. The field scientist will determine when static equilibrium has been reached in the well. The pressure transducer, slugs, and any other downhole equipment will be decontaminated prior to and immediately after the performance of each slug test using the procedures described in Section 3.3.1.1.

3.5.1.4 Falling Head Test

The falling head test is the first step in the two-step slug testing procedure. The following steps describe procedures to be followed during performance of the falling head test.

1. Decontaminate all downhole equipment prior to initiating the test.
2. Open the well. Where wells are equipped with watertight caps, the well should be unsealed at least 24 hours prior to testing to allow the water level to stabilize. The protective casing will remain locked during this time to prevent vandalism.
3. Prepare the aquifer slug test data form (Figure 3.6) with entries for:
 - Borehole/well number,
 - Project number,
 - Project name,
 - Aquifer testing team,
 - Climatic data,

Aquifer Slug Test Data Sheet

Location <u>Hill AFB</u>	Client <u>AFCEE</u>	Well No. _____
Job No. _____	Field Scientist _____	Date _____
Water Level _____	Total Well Depth _____	
Measuring Datum <u>TOC</u>	Elevation of Datum _____	
Weather _____	Temp _____	
Comments _____		

[illegible]

FIGURE 3.6

AQUIFER TEST DATA FORM

Hill Air Force Base, Utah

**PARSONS
ENGINEERING SCIENCE, INC.**

- Ground surface elevation,
 - Top of well casing elevation,
 - Identification of measuring equipment being used,
 - Page number,
 - Static water level, and
 - Date.
4. Measure the static water level in the well to the nearest 0.01 foot.
 5. Lower the decontaminated pressure transducer into the well and allow the displaced water to return to its static level. This can be determined by periodic water level measurements until the static water level in the well is within 0.01 foot of the original static water level.
 6. Lower the decontaminated slug into the well to just above the water level in the well.
 7. Turn on the data logger and quickly lower the slug below the water table, being careful not to disturb the pressure transducer. Follow the owner's manual for proper operation of the data logger.
 8. Terminate data recording when the water level stabilizes in the well. The well will be considered stabilized for termination purposes when it has recovered 80 to 90 percent from the initial displacement.

3.5.1.5 Rising Head Test

After completion of the falling head test, the rising head test will be performed. The following steps describe the rising head slug test procedure.

1. Measure the water level in the well to the nearest 0.01 foot to ensure that it has returned to the static water level.
2. Initiate data recording and quickly withdraw the slug from the well. Follow the owner's manual for proper operation of the data logger.

3. Terminate data recording when the water level stabilizes in the well, and remove the pressure transducer from the well and decontaminate. The well will be considered stabilized for termination purposes when it has recovered 80 to 90 percent from the initial displacement.

3.5.1.6 Slug Test Data Analysis

Data obtained during slug testing will be analyzed using AQTESOLV™ (Geraghty & Miller, Inc., 1994), which employs the method of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions.

3.5.2 Downhole Flowmeter Testing

Downhole flowmeter tests will be conducted to investigate the relative vertical distribution of horizontal hydraulic conductivity in upper portion of saturated zone and to identify any zones of elevated hydraulic conductivity. To do so, personnel will perform electromagnetic borehole flowmeter surveys in up to five previously installed monitoring wells using the methodology of Molz *et al.* (1994). Additional wells may be surveyed depending on availability and preliminary test results. These tests will be done to identify fast flow zones that may accelerate contaminant migration within the shallow groundwater system. Preferably, wells to be flow tested will be those that are also slug tested for hydraulic conductivity

3.5.2.1 Experiment Design

Flowmeter measurements will be performed at 1- to 3-foot intervals below the water table during both ambient conditions and induced flow conditions. The test data will be analyzed using the methods described by Molz *et al.* (1994) to define the relative distribution of horizontal hydraulic conductivity within the screened interval of each well. Final results will be presented in tabular and graphical forms and accompanied by appropriate interpretation and discussion. Estimates of bulk hydraulic conductivity from previous aquifer tests or results of the single-well tests conducted during this survey will be used to estimate the absolute hydraulic conductivity distribution at each well.

3.5.2.2 Procedure

The borehole flowmeter will be calibrated prior to departure for Hill AFB. The 0.5-inch-ID and 1.0-inch-ID probes will be calibrated using a range of volumetric flow rates potentially applicable to this demonstration [e.g., approximately 0.04 liters per minute (L/min) to 10 L/min].

The flowmeter survey will be conducted in each well using the following procedure:

1. Water level, organic liquid NAPL interfaces (if present), and total depth (TD) will be measured prior to test initiation.
2. Depending on site conditions, flowmeter measurements using the 0.5-inch-ID probe will be obtained at 1- to 3-foot intervals starting at TD and proceeding up the well under static (ambient) conditions.
3. A short-term, single-well pumping test will be conducted in the test well to stress the aquifer. Drawdown will be measured and recorded using an electronic datalogger with a pressure transducer. The groundwater extraction rate will be monitored and adjusted, as necessary, to maintain constant flow. Extracted groundwater will be contained for disposal by site personnel. It is estimated that extraction rates may range from less than 1 L/min to approximately 10 L/min, and that the test duration may range from 1 to 4 hours.
4. Upon stabilization of the flow rate, the profile of vertical flow will be obtained using the 1.0-inch-ID probe at the same elevations occupied during the ambient profile.
5. Data collected during the tests will be analyzed to estimate relative distribution of flow to the wells and the relative hydraulic conductivity distribution at each location.

All downhole test equipment will be properly decontaminated between tests at different monitoring wells.

3.5.3 Spring Discharge Rate Measurement

Where possible, volumetric rates of groundwater discharge at springs and seeps will also be measured during the field effort. As with sampling of the springs, the method used to determine discharge rates will depend on the nature of the spring.

3.6 MICROCOSM STUDIES

Microcosm studies may be performed on selected soil samples collected at OU 4 to confirm biodegradation of CAHs. Because microcosm studies are time-consuming and expensive, they should be undertaken only at sites where there is considerable uncertainty concerning the biodegradation of CAHs based on soil and groundwater samples alone. If biodegradation is occurring, these microcosms also will help determine which mechanisms of biodegradation are operating at the site.

If properly designed, implemented, and interpreted, microcosm studies can provide very convincing documentation of the occurrence of natural bioremediation. They are the only "line of evidence" that allows an unequivocal mass balance on the biodegradation of environmental contaminants. If the microcosm study is properly designed, the results will be easy for decision makers with differing technical backgrounds to interpret. The results of a microcosm study are strongly influenced by the nature of the geological material submitted for the study, the physical properties of the microcosm, the sampling strategy, and the duration of the study.

3.6.1 Microcosm Sample Collection

Saturated soil and groundwater samples for microcosm construction will be collected using the Geoprobe[®] system. Ideally, samples collected for microcosms will meet the following conditions: 1) soils and groundwater will be collected minimum of 3 feet below the groundwater surface to minimize oxygen contamination, 2) TCE concentrations in the groundwater/pore water will be greater than 1 mg/L to guarantee compound resolution throughout the microcosm studies, and 3) only sands or other granular materials should be used for microcosm construction. In the event that soils are highly plastic in the areas selected for microcosm materials collection, additional punches must be performed in the vicinity to locate soils with permeabilities greater than a fine sand. If any of these conditions are not met, microcosm study results may be compromised.

The soil cores will be retained within brass, stainless steel, clear acetate, or Teflon[®] liners inside the sampling barrel. The soil sample can then be extruded from the liners for logging, or the liners can be capped and undisturbed samples submitted to the analytical laboratory for testing and microcosm construction. Transferring the saturated aquifer media from the soil sampling device will be conducted in a manner that minimizes environmental exposure and maintains the original physical, chemical, and biological characteristic. The greater the care taken to maintain *in situ* conditions in the microcosm cores, the greater correlation the microcosm data will have to the field scale. The soil sampling device will be retracted quickly from the ground to reduce any potential soil and groundwater loss from the downhole end the sampling apparatus. Furthermore, rapid extraction from the subsurface will help minimize aeration of samples taken from anoxic and anaerobic zones.

Additional groundwater will be collected during soils acquisition. Groundwater will be used to displace the headspace in soil collection jars. Additional groundwater volumes also may be needed for microcosm construction at the USEPA NRMRL in Ada, Oklahoma. Shallow groundwater will be extracted with peristaltic pumps, bailers, or other devices, depending upon site conditions.

All soil and groundwater samples collected in wide-mouth jars will be collected and stored to minimize oxygen contamination. The jars containing site media will be cooled to 4 degrees Celsius (°C) and packed in a manner to prevent accidental breakage during shipment. Coolers will be shipped via an overnight courier to be received by the laboratory the morning following sampling.

3.6.2 Microcosm Construction and Sampling

Trained personnel will be responsible for construction and sampling of the microcosms. Standard microcosm procedures, including use of sterilized controls, will be followed to complete this study. These procedures will follow those general procedures as outlined at the beginning of Section 3.6.

Batch microcosms that are sacrificed for each analysis usually give more interpretable results than column microcosms or batch microcosms that are sampled repetitively. For statistical reasons, at least three microcosms should be sampled at each time interval. If one assumes a first-order rate law, and no lag, a geometrical time interval for sampling should be the most efficient. An example would be sampling after 0 week, 2 weeks, 1 month, 2 months, 4 months, and 8 months. As a practical matter, long lags frequently occur, and the rate of bioremediation after the lag is rapid; therefore, a simple linear time scale is most likely to give interpretable results. Sampling intervals may be adjusted as the data are collected.

Microcosms are inherently time consuming. At field scale, the residence time of a plume may be several years to decades, and slow rates of transformation may have a considerable environmental significance. A microcosm study that lasts only a few weeks or months may not have the resolution to detect slow changes that are still of environmental significance. Further, microcosms often show a pattern of sequential utilization, with certain contaminants degrading first, and others degrading at a later time. Degradation of some compounds may be delayed by as much as a year.

The batch microcosms should have approximately the same ratio of solids to water as the original material. Most of the microbes are attached to solids. Therefore, if a microcosm has excess water, and the contaminant is mostly in the aqueous phase, the

microbes must process a great deal more contaminant to produce the same relative change in the contaminant concentration. The kinetics at the field scale would be underestimated.

As a practical matter, batch microcosms with an optimal solids-to-water ratio, sampled every 2 months in triplicate for up to 18 months, can resolve biodegradation losses from abiotic losses with a rate detection limit of 0.001 to 0.0005 per day. Many plumes show significant attenuation of contamination at field-calibrated rates that are slower than these detection limits. The most appropriate use of microcosms is to document that contaminant attenuation is largely a biological process. Rate constants for modeling purposes are more appropriately acquired from field-scale studies.

SECTION 4

QUALITY ASSURANCE/QUALITY CONTROL

Field QA/QC procedures appropriate to a typical site investigation should be followed for the RNA demonstration. If necessary, these procedures should follow appropriate regulatory guidelines, or should be agreed upon by all involved parties. The following suggested procedures are typically suitable for an RNA demonstration.

Field QA/QC procedures will include collection of field duplicates and rinseate, field and trip blanks; decontamination of all equipment that contacts the sample medium before and after each use; use of analyte-appropriate containers; and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., groundwater), and analyses requested. Samples will be preserved in accordance with the analytical methods to be used, and sample containers will be packaged in coolers with ice to maintain a temperature of as close to 4°C as possible.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature. Field QC samples will be collected in accordance with the program described below, and as summarized in Table 4.1.

QA/QC sampling will include collection and analysis of duplicate groundwater and replicate soil samples, rinseate blanks, field/trip blanks, and matrix spike samples. Internal laboratory QC analyses will involve the analysis of laboratory control samples (LCSs) and laboratory method blanks (LMBs). QA/QC objectives for each of these samples, blanks, and spikes are described below.

Duplicate water and replicate soil samples will be collected at a frequency of 1 for every 10 of similar matrix. Soil and groundwater samples collected with the Geoprobe[®] sampler should provide sufficient volume for some replicate/duplicate analyses. Refer to Table 3.1 and Appendix E for further details on sample volume requirements.

TABLE 4.1
QA/QC SAMPLING PROGRAM
Hill Air Force Base, Utah

QA/QC Sample Types	Frequency to be Collected and/or Analyzed	Analytical Methods
Duplicates/Replicates	5 Groundwater and 1 Soil Samples (10%)	VOCs
Rinseate Blanks	3 Samples (5% of Groundwater Samples)	VOCs
Field Blanks	3 Samples (5% of Groundwater Samples)	VOCs
Trip Blanks	One per shipping cooler containing VOC samples	VOCs
Matrix Spike Samples	Once per sampling event	VOCs
Laboratory Control Sample	Once per method per medium	Laboratory Control Charts (Method Specific)
Laboratory Method Blanks	Once per method per medium	Laboratory Control Charts (Method Specific)

One rinseate sample will be collected for every 20 or fewer groundwater samples collected from existing wells. Because disposable bailers may be used for this sampling event, the rinseate sample will consist of a sample of distilled water poured into a new disposable bailer and subsequently transferred into a sample container provided by the laboratory. Rinseate samples will be collected and analyzed for VOCs only.

A field blank will be collected for every 20 or fewer groundwater samples (both from groundwater monitoring point and groundwater monitoring well sampling events) to assess the effects of ambient conditions in the field. The field blank will consist of a sample of distilled water poured into a laboratory-supplied sample container while sampling activities are underway. The field blank will be collected and analyzed for VOCs.

A trip blank will be analyzed to assess the effects of ambient conditions on sampling results during the transportation of samples. The trip blank will be prepared by the laboratory. A trip blank will be transported inside each cooler which contains samples for VOC analysis. Trip blanks will be analyzed for VOCs.

Matrix spikes will be prepared in the laboratory and used to establish matrix effects for samples analyzed for VOCs. LCSs and LMBs will be prepared internally by the laboratory and will be analyzed each day samples from the site are analyzed. Samples will be reanalyzed in cases where the LCS or LMB are out of the control limits. Control charts for LCSs and LMBs will be developed by the laboratory and monitored for the analytical methods used (see Table 3.1).

SECTION 5

DATA ANALYSIS AND REPORT

Data collected during the field effort (protocol parameter sampling and potential intrusive work) will be analyzed using a variety of methods. For example, isopleth maps of CAHs, degradation products, and alternate electron acceptors and donors will be used to evaluate the occurrence and mechanisms of biodegradation at the site. The Thiessen method will be used to estimate contaminant mass in the plume using data from the more recent sampling events and from previous sampling events. The Thiessen method also may be used to evaluate movement of the center of mass of the CAH plume over time, as presented by Dupont *et al.* (1996a and 1996b). This information will give an indication of how the plume has changed over time and if it is stable. If contaminant mass diminishes over time, then it is likely that RNA is occurring. Necessarily, the potential impacts of the current OU 4 remedial actions on RNA will be evaluated and factored into the mass loss scenario for OU 4, and potential continuing sources will be further evaluated. In addition, site contaminant data will be used to determine rates of contaminant mass loss, and in conjunction with microcosm data (if collected), to determine rates of biodegradation. The data also will be used to estimate contaminant mass flux through specified areas and to estimate volumetric mass discharge.

In conjunction with the data evaluation and analysis, numerical and/or analytical groundwater models will be used to evaluate the fate and transport of chlorinated solvents dissolved in groundwater at the site. The contaminant fate and transport modeling effort has three primary objectives: 1) predict the future extent and concentration of dissolved contaminant plumes by modeling the effects of advection, dispersion, sorption, and biodegradation; 2) assess the possible exposure of potential downgradient receptors to contaminant concentrations that exceed levels intended to be protective of human health and the environment; and 3) to provide technical support for selection of RNA as a viable remedial alternative.

Based on model predictions of contaminant concentrations and distribution through time, and on potential exposure pathways, the potential for receptors to be exposed to contaminant concentrations that could threaten human health and the environment will be assessed. If apparent that RNA of CAHs at the site is sufficient to reduce the potential threat to human health and the environment to acceptable levels, within an acceptable

time-frame, an RNA option will be recommended. A comprehensive report detailing the field effort and analysis of RNA will be prepared.

If RNA is chosen as a remedial option, a site-specific LTM plan that specifies the location and sampling frequency of point-of-compliance monitoring wells will be prepared. If the RNA remedial option is deemed inappropriate for sole use at the site or use in conjunction with other potential remedial options, institutional controls such as groundwater or land use restrictions could be evaluated. If institutional controls are inappropriate, planned or potential engineered remedial designs are an option. The reduction in dissolved contaminant concentrations that should result from remedial activities could be used to produce new input files for the groundwater models. The models could then be used to predict the plume (and risk) reduction that should result from remedial actions.

SECTION 6

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FINAL

APPENDIX A

HYDROGEOLOGICAL AND GEOTECHNICAL DATA

Table A.1 Estimated horizontal hydraulic conductivity
values determined from slug tests for selected wells
in the area of Operable Unit 4

Well number	Depth to water (feet below land surface)	Screened interval (feet below land surface)	Hydraulic conductivity ¹ (feet/day)
LF1T-1	24.5	24.5-56.3	1
LF2T-1	17.8	40.7-61.5	0.1
LF1GS1	31.9	30.3-40.3	0.01
LF1GS3A	13.6	30.3-40.3	0.01
LF1GS3B	15.3	9.3-24.3	0.01
LF1GS4A	12.3	35.3-45.3	0.01
LF1GS4B	11.0	19.0-29.0	1
LF1GS5	15.7	15.3-25.3	1
LF1GS6	19.8	22.3-37.3	1
P2	12.1	19.5-39.5	0.01
P3	18.8	20.5-30.5	1
P4	16.1	11.5-31.5	1
P5B	17.2	44.5-64.5	0.1
P7	6.9	34.5-44.5	0.01
P8	12.3	13.5-28.5	0.1
P10	23.8	40.0-50.0	0.1
P10A	12.2	13.0-33.0	10
P11	9.7	10.0-30.0	0.1
P17	29.7	49.5-64.5	0.01
P18	30.0	30.0-40.0	1
P19	20.6	49.5-69.5	0.001
P20	15.5	38.0-58.0	1
P21	13.1	37.0-52.0	0.1
P22	32.5	39.0-59.0	1
P23	30.4	30.0-50.0	0.01

¹Rounded to the nearest order of magnitude.

Table A.2 Geotechnical properties of subsurface sediments
in the area of Operable Unit 4
[lb/ft³, pounds per cubic foot; meq/gr, milliequivalents per gram; --, no data]

Well number	Depth (feet)	Specific gravity	Porosity	Vertical hydraulic conductivity (feet/day)	Natural dry density (lb/ft ³)	Moisture content (percent)	Cation exchange capacity (meq/100g)	Organic matter (percent)	Limits		Plasticity index (percent)
									Liquid (percent)	Plastic (percent)	
LF1GS3A	12-14	--	0.43	1.4x10 ⁻⁵	96.1	28.2	18.5	0.35	38	19	19
	22-24	--	0.51	2.7x10 ⁻¹	82.0	26.8	13.8	1.28	24	20	4
	37-39	--	0.46	2.1x10 ⁻⁴	93.3	28.8	15.3	0.70	37	19	18
LF1GS4A	11-13	--	0.41	2.7x10 ⁻³	99.5	16.9	10.0	0.21	29	17	12
	17-19	--	0.38	6.0x10 ⁻⁵	104.9	19.5	12.1	0.44	31	17	14
	22-24	--	0.41	7.4x10 ⁻⁵	99.5	24.0	14.0	0.32	30	17	13
	27-29	--	0.42	1.1x10 ⁻⁴	98.1	27.0	20.5	0.53	39	19	20
	32-34	--	0.42	3.1x10 ⁻⁴	98.4	24.8	16.8	0.81	34	17	17
	39-41	--	0.48	1.9x10 ⁻⁴	88.2	22.6	14.7	0.84	34	18	16
	42-44	--	0.42	7.4x10 ⁻⁵	98.6	24.5	11.5	0.66	29	16	13
PSA	9-10	2.70	0.48	2.8x10 ⁻⁴	88.0	14.0	11.6	1.90	33	15	18
	19-21	2.67	0.42	2.8x10 ⁻⁴	97.0	29.0	10.1	0.99	33	18	15
	25-27	2.78	0.42	1.1x10 ⁻⁴	101.0	26.0	9.4	1.03	27	19	8
PSB	9-11	2.73	0.39	1.1x10 ⁻⁴	104.0	16.0	12.0	1.55	41	16	25
	19-21	2.69	0.41	1.4x10 ⁻⁴	98.0	25.0	15.0	1.43	31	17	14
	29-31	2.74	0.52	1.7x10 ⁻⁴	82.0	40.0	13.7	1.36	40	21	19
	39-41	2.69	0.40	5.7x10 ⁻⁵	100.0	25.0	15.0	1.25	34	19	15
	49-51	2.74	0.40	5.7x10 ⁻⁵	103.0	25.0	11.3	0.86	33	19	14
	59-61	2.70	0.44	5.7x10 ⁻⁵	95.0	29.0	14.3	1.66	38	20	18
P7	9-11	2.78	0.58	2.3x10 ⁻²	73.0	19.0	10.1	0.68	30	15	15
	19-21	2.73	0.41	1.4x10 ⁻³	100.0	23.0	15.1	0.82	40	17	23
	32-34	2.74	0.42	5.7x10 ⁻⁴	98.0	26.0	11.8	1.11	24	17	7
	44-46	2.70	0.42	5.7x10 ⁻⁵	98.0	26.0	13.2	1.56	33	17	16
P10	21-22.5	2.55	0.37	1.8x10 ⁻⁴	100.0	24.0	11.7	1.51	33	16	17
	39.5-41	2.55	0.38	4.3x10 ⁻⁴	98.0	25.0	16.1	2.13	42	18	24
P11	24-25	2.81	0.42	4.0x10 ⁻⁵	102.0	21.0	12.6	1.84	31	16	15
	35-37.5	2.74	0.43	6.5x10 ⁻⁵	97.0	26.0	9.1	1.91	36	18	18
P17	36-38	2.69	0.40	1.4x10 ⁻⁴	101.0	26.0	15.8	1.53	41	20	21
P20	9-11	2.70	0.56	1.7x10 ⁻⁵	74.0	18.0	12.2	2.12	35	15	20
	19-21	2.69	0.40	8.5x10 ⁻⁶	100.0	20.0	12.9	1.66	34	16	18
	29-31	2.67	0.40	2.3x10 ⁻⁵	100.0	27.0	15.5	2.54	31	18	13
	39-41	2.66	0.41	8.5x10 ⁻⁶	98.0	27.0	15.0	2.33	--	--	--
	49-51	2.70	0.43	2.0x10 ⁻³	96.0	29.0	12.9	2.20	28	18	10
	59-61	2.68	0.42	5.7x10 ⁻⁵	97.0	26.0	3.0	0.85	--	--	--
	69-71	2.71	0.42	2.0x10 ⁻⁴	98.0	27.0	8.2	1.90	25	19	6
	79-81	2.67	0.41	8.5x10 ⁻²	99.0	25.0	3.6	0.76	--	--	--
	89-91	2.67	0.43	2.8x10 ⁻⁴	95.0	30.0	11.1	1.76	24	19	5
P22	12.5-14	2.59	--	--	--	17.0	15.2	2.71	30	17	13
	17.5-19	2.65	0.38	6.2x10 ⁻⁵	103.0	20.0	13.5	1.61	38	16	22
	21-24	2.71	0.38	9.1x10 ⁻⁵	105.0	19.0	17.8	1.50	38	17	21
	26-29	2.60	0.36	2.6x10 ⁻⁵	105.0	21.0	14.4	1.32	39	20	19
	31-34	2.69	0.40	6.8x10 ⁻³	100.0	25.0	4.8	0.74	33	17	16
	44-46	2.57	0.38	2.2x10 ⁻³	99.0	26.0	1.30	0.36	26	19	7
P25	19.5-21.5	2.72	0.39	7.7x10 ⁻⁵	104.0	21.0	14.4	1.71	39	18	21

Table A.3 Apparent vertical and horizontal linear velocities for selected well clusters in the area of Operable Unit 4

[Normalized water-level differences: water-level differences were normalized to account for horizontal gradients; Equivalent vertical hydraulic conductivity calculated from laboratory measurements on cores of sediments (see table 4.5.2.1.2-1)]

Well cluster	Distance between midpoints of screened interval (feet)	Normalized water-level difference (feet)	Vertical hydraulic gradient (iv) (foot/foot)	Equivalent vertical hydraulic conductivity (Kv) (foot/day)	Average porosity	Apparent average linear velocity					
						Vertical (using maximum Iv) (feet/day) (foot/year)	Horizontal ¹ (feet/day) (feet/year)				
Shallow		Minimum	Maximum								
Deep		Maximum	Minimum								
LF1GS3B	17.7	-2.9	0.33	-0.16	0.019	3.9×10^{-5}	0.47	0.16×10^{-5}	0.00058	.006	2.2
LF1GS4B	16.6	0.10	1.7	0.0060	0.10	11×10^{-5}	0.42	2.6×10^{-5}	0.0095	.2	73
P17	22.9	-0.54	4.0	-0.024	0.17	14×10^{-5}	0.40	5.9×10^{-5}	0.021	.2	73
P5A	32.5	-1.4	6.4	-0.043	0.20	8.0×10^{-5}	0.43	3.7×10^{-5}	0.013	.4	146

¹ Horizontal velocities were calculated using the hydraulic-conductivity values determined from slug tests for the shallow well in a well cluster, hydraulic gradients estimated from potentiometric contours, and average porosities.

FINAL

APPENDIX B

VOCS DETECTED IN GROUNDWATER (1986-1995)

Appendix B. Concentrations of volatile organic compounds in water from wells and a seep in the area of Operable Unit 4, Hill Air Force Base, Utah

[TCE, trichloroethylene; 1,1,2-DCE, trans-1,2-dichloroethylene; MC, methylene chloride; 1,2-DCA, 1,2-dichloroethane; 1,1-DCE, 1,1-dichloroethylene; PCE, tetrachloroethylene; MEK, methyl ethyl ketone; µg/L, micrograms per liter; ND, not detected (detection limits are in parentheses); NA, data not available; D, blind duplicate analysis; B, compound was also found in the associated trip or equipment blank; R, data invalid (U.S. Environmental Protection Agency, Human Health Evaluation Manual, 1989); **, data collected by Montgomery Watson, Incorporated.; Water-quality standards: PMCL; primary maximum contaminant level; MCL, Maximum Contaminant Level was established by the U.S. Environmental Protection Agency's Safe Drinking Water Act; NE, not established; pHA, proposed health advisory level; pMCL, proposed maximum contaminant level]

Well	Date sampled	TCE (µg/L)	1,1,2-DCE ¹ (µg/L)	Benzene (µg/L)	Chloroform (µg/L)	MC (µg/L)	1,2-DCA (µg/L)	1,1-DCE (µg/L)	PCE (µg/L)	Acetone (µg/L)	MEK (µg/L)	Toluene (µg/L)	Xylenes (µg/L)	
Water- quality standard	Upgradient from Canal													
	5.0 PMCL	2100 PMCL	5.0 PMCL	3100 MCL	NE	5.0 PMCL	7.0 PMCL	7.0 PMCL	NE	170 pHA	1,000 pMCL	1,000 pMCL	1,000 pMCL	
LFIT-1	4,185	ND (100)	NA	ND (50)	ND (250)	ND (30)	ND (130)	ND (30)	NA	NA	NA	NA	NA	
	832	ND (10)	ND(200)	ND (90)	ND (250)	ND (90)	ND (490)	ND (30)	NA	NA	NA	ND (200)	NA	
	1,500	ND (50)	ND (30)	ND (50)	ND (70)	ND (30)	ND (30)	ND (30)	110	120	120	ND (50)	ND (50)	
	1,200	ND (50)	ND (30)	ND (50)	ND (50)	ND (30)	ND (30)	ND (30)	ND (100)	ND (100)	ND (100)	ND (50)	ND (50)	
	510	ND (25)	ND (15)	ND (25)	ND (85)	ND (15)	ND (20)	ND (15)	ND (250)	ND (250)	ND (250)	ND (25)	ND (25)	
	340	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (500)	ND (500)	ND (50)	ND (50)	
	400	ND (12)	ND (12)	ND (12)	ND (42)	ND (12)	ND (10)	ND (12)	ND (120)	ND (120)	ND (120)	ND (12)	ND (12)	
	190	ND (25)	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (250)	ND (25)	ND (25)	
	210	ND (6.2)	ND (6.2)	ND (6.2)	ND (21)	ND (6.2)	ND (5)	ND (6.2)	ND (62)	ND (62)	ND (62)	ND (6.2)	ND (6.2)	
	150	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	
	240	ND (12)	ND (12)	ND (12)	ND (42)	ND (12)	ND (10)	ND (12)	ND (120)	ND (120)	ND (120)	ND (12)	ND (12)	
	460	ND (17)	ND (17)	ND (17)	ND (57)	ND (17)	ND (13)	ND (17)	ND (170)	ND (170)	ND (170)	ND (17)	ND (17)	
	340	ND (12)	ND (12)	ND (12)	ND (42)	ND (12)	ND (10)	ND (12)	ND (120)	ND (120)	ND (120)	ND (12)	ND (12)	
	320	ND (12)	ND (12)	ND (12)	ND (12)	ND (42)	ND (10)	ND (12)	ND (120)	ND (120)	ND (120)	ND (12)	ND (12)	
	400	ND (10)	ND (10)	ND (10)	ND (34)	ND (10)	ND (8)	ND (10)	ND (100)	ND (100)	ND (100)	ND (10)	ND (10)	
	310	ND (12)	ND (12)	ND (12)	ND (42)	ND (12)	ND (10)	ND (12)	ND (120)	ND (120)	ND (120)	ND (12)	ND (12)	
(D)	320	ND (12)	ND (12)	ND (12)	ND (42)	ND (12)	ND (10)	ND (12)	ND (120)	ND (120)	ND (120)	ND (12)	ND (12)	
	300	ND (12)	ND (12)	ND (12)	ND (42)	ND (12)	ND (10)	ND (12)	ND (120)	ND (120)	ND (120)	ND (12)	ND (12)	
	380	ND (25)	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (250)	ND (25)	ND (25)	
	400	ND (25)	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (250)	ND (25)	ND (25)	
	600	ND (25)	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (250)	ND (25)	ND (25)	
	600	ND (25)	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (250)	ND (25)	ND (25)	
LFIT-1	6.08	ND (0.10)	NA	ND (0.05)	ND (0.98)	ND (0.03)	ND (0.13)	ND (0.03)	NA	NA	NA	NA	NA	
	11.5	ND (0.10)	2.32	ND (0.09)	ND (0.25)	ND (0.09)	ND (0.49)	ND (0.5)	NA	NA	NA	ND (0.2)	NA	
	10	6.4	ND (3)	ND (5)	ND (7)	ND (3)	ND (3)	ND (3)	ND (10)	ND (10)	ND (10)	ND (5)	ND (5)	
	13	5.4	ND (3)	ND (5)	ND (5)	ND (3)	ND (3)	ND (3)	ND (10)	ND (10)	ND (10)	ND (5)	ND (5)	
	9.6	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	
	11	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	
	21	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	
	17	7.2	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	
	23	11	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	
	21	11	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	
	29	14	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	
	19	8.9	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	
	26	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	
	LFIGS1	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	NA	NA	NA	ND (1)	NA
		ND (3)	ND (3)	ND (3)	ND (3)	ND (3)	ND (3)	ND (3)	ND (3)	ND (10)	ND (10)	ND (10)	ND (5)	ND (5)
		ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)

Appendix B. Concentrations of volatile organic compounds in water from wells and a seep in the area of Operable Unit 4, Hill Air Force Base, Utah—Continued

Well	Date sampled	TCE (µg/L)	Upgradient from Canal—Continued													
			1,1,2-DCE ¹ (µg/L)	Benzene (µg/L)	Chloroform (µg/L)	MC (µg/L)	1,2-DCA (µg/L)	1,1-DCE (µg/L)	PCE (µg/L)	Acetone (µg/L)	MEK (µg/L)	Toluene (µg/L)	Xylenes (µg/L)			
LF1GS3A	Water- quality standard	5.0 PMCL	2100 PMCL	5.0 PMCL	3100 MCL	NE	5.0 PMCL	7.0 PMCL	7.0 PMCL	NE	170 pHA	1,000 PMCL	1,000 PMCL			
		ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	NA	NA	ND (10)	ND (1)	NA		
		ND (3)	ND (5)	ND (3)	ND (5)	ND (5)	ND (3)	ND (3)	ND (3)	ND (10)	ND (10)	ND (5)	ND (5)	ND (5)		
		ND (3)	ND (5)	ND (3)	ND (5)	ND (17)	ND (3)	ND (4)	ND (3)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)		
		ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)		
		ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)		
		ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)		
		ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)		
		ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)		
		ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)		
		ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)		
		ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)		
LF1GS3B		5.044	124	ND (1)	4.6	ND (1)	1.5	1.4	1.0	NA	NA	ND (10)	67	NA		
		5.4	ND (5)	ND (3)	ND (25)	ND (5)	ND (3)	ND (3)	ND (3)	ND (10)	ND (10)	ND (2500)	ND (250)	7.5		
		9.300	270	ND (150)	ND (250)	ND (850)	ND (150)	ND (200)	ND (150)	ND (2,500)	ND (2,500)	ND (1200)	ND (120)	ND (250)		
		3.600	ND (120)	ND (75)	ND (120)	ND (420)	ND (75)	ND (100)	ND (75)	ND (1,200)	ND (1,200)	ND (250)	ND (250)	ND (250)		
		3.700	ND (250)	ND (250)	ND (250)	ND (850)	ND (250)	ND (200)	ND (250)	ND (2,500)	ND (2,500)	ND (500)	ND (50)	ND (85)		
		1.700	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (500)	ND (850)	ND (100)	ND (100)		
		2.800	ND (85)	ND (85)	ND (85)	ND (290)	ND (85)	ND (68)	ND (85)	ND (850)	ND (850)	ND (500)	ND (50)	ND (50)		
		3.100	ND (100)	ND (100)	ND (100)	ND (340)	ND (100)	ND (80)	ND (100)	ND (1,000)	ND (1,000)	ND (100)	ND (100)	ND (100)		
		1.600	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (500)	ND (360)	ND (36)	ND (36)		
		3.600	ND (100)	ND (100)	ND (100)	ND (100)	ND (100)	ND (50)	ND (100)	ND (100)	ND (100)	ND (500)	ND (50)	ND (50)		
		3.300	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (500)	ND (50)	ND (50)		
		2.500	ND (100)	ND (100)	ND (100)	ND (340)	ND (100)	ND (80)	ND (100)	ND (1,000)	ND (1,000)	ND (100)	ND (100)	ND (100)		
(D)		3.800	ND (110)	ND (110)	ND (110)	ND (390)	ND (110)	ND (91)	ND (110)	ND (1,000) <td>ND (1,000)</td> <td>ND (110)</td> <td>ND (110)</td> <td>ND (110)</td>	ND (1,000)	ND (110)	ND (110)	ND (110)		
		2500	ND (100)	ND (100)	ND (100)	ND (340)	ND (100)	ND (80)	ND (100)	ND (1,000)	ND (1,000)	ND (100)	ND (100)	ND (100)		
		2500	ND (100)	ND (100)	ND (100)	ND (340)	ND (100)	ND (80)	ND (100)	ND (1,000)	ND (1,000)	ND (100)	ND (100)	ND (100)		
		1100	ND (36)	ND (36)	ND (36)	ND (120)	ND (36)	ND (29)	ND (36)	ND (360)	ND (360)	ND (36)	ND (36)	ND (36)		
		1300	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (500)	ND (50)	ND (50)	ND (50)		
		2700	ND (84)	ND (84)	ND (84)	ND (280)	ND (84)	ND (67)	ND (84)	ND (840)	ND (840)	ND (84)	ND (84)	ND (84)		
		LF1GS4A		19	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	ND (1)	NA	NA	ND (10)	ND (1)	NA
				15	ND (5)	ND (3)	ND (5)	14BR	ND (3)	ND (3)	ND (3)	ND (10)	ND (10)	ND (5)	ND (5)	ND (5)
				9.1	ND (5)	ND (3)	ND (5)	ND (17)	ND (3)	ND (4)	ND (3)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
				12	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
				16	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
				21	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
45	ND (5)			ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)		
210	ND (6.2)			ND (6.2)	ND (6.2)	ND (21)	ND (6.2)	ND (5)	ND (6.2)	ND (62)	ND (62)	ND (62)	ND (6.2)	ND (6.2)		
230	ND (8.3)			ND (8.3)	ND (8.3)	ND (28)	ND (8.3)	ND (8.3)	ND (8.3)	ND (84)	ND (84)	ND (84)	ND (8.3)	ND (8.3)		
120	5.1			ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)		
97	5.0			ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)		
180	ND (5)			ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)		

(D)

Upgradient from Canal—Continued—

**Water-
quality
standard**

Appendix B. Concentrations of volatile organic compounds in water from wells and a seep in the area of Operable Unit 4, Hill Air Force Base, Utah—Continued

Well	Date sampled	Upgradient from Canal—Continued											
		TCE (µg/L)	1,1,2-DCE ¹ (µg/L)	Benzene (µg/L)	Chloroform (µg/L)	MC (µg/L)	1,2-DCA (µg/L)	1,1-DCE (µg/L)	PCE (µg/L)	Acetone (µg/L)	MEK (µg/L)	Toluene (µg/L)	Xylenes (µg/L)
Water- quality standard		5.0 PMCL	2 ¹ 100 PMCL	5.0 PMCL	3 ¹ 100 MCL	NE	5.0 PMCL	7.0 PMCL	NE	170 pHA	1,000 PMCL	1,000 PMCL	1,000 PMCL
P5B	06/15/89	67	ND	ND (3)	ND (5)	ND (17)	ND (3)	ND (4)	ND (3)	ND (50)	ND (50)	ND (5)	ND (5)
	10/18/89	9.3	ND	ND (3)	ND (5)	ND (17)	ND (3)	ND (4)	ND (3)	ND (50)	ND (50)	ND (5)	ND (5)
	04/02/91	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	6.8
	10/28/91	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
	10/28/91	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
(D)	07/15/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
	04/07/93	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
	06/01/94	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
	05/17/95	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
	05/05/89	ND (3)	ND (5)	ND (3)	ND (5)	ND (17)	ND (3)	ND (4)	ND (3)	ND (50)	ND (50)	ND (5)	ND (5)
P17	03/21/91	8	ND	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
	10/17/91	8.3	ND	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
	07/08/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
	05/05/89	600	ND	ND (10)	ND (16)	ND (56)	ND (10)	ND (13)	ND (10)	ND (160)	ND (160)	ND (16)	ND (16)
	10/25/89	550	ND	ND (15)	ND (25)	ND (85)	ND (15)	ND (20)	ND (15)	ND (250)	ND (250)	ND (25)	ND (25)
(D)	10/25/89	530	ND	ND (15)	ND (25)	ND (85)	ND (15)	ND (20)	ND (15)	ND (250)	ND (250)	ND (25)	ND (25)
	03/28/91	410	ND	ND (16)	ND (16)	ND (56)	ND (16)	ND (13)	ND (16)	ND (160)	ND (160)	ND (16)	ND (16)
	10/17/91	420	ND	ND (16)	ND (16)	ND (56)	ND (16)	ND (13)	ND (16)	ND (160)	ND (160)	ND (16)	ND (16)
	09/22/92	350	ND	ND (10)	ND (10)	ND (34)	ND (10)	ND (8)	ND (10)	ND (100)	ND (100)	ND (10)	ND (10)
	06/07/94	460	ND	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (25)	ND (25)
U4-33	06/05/95	400	ND	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (25)	ND (25)
	05/06/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
	10/22/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
	04/16/93	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
	11/03/93	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
(D)	05/10/94	-ND-	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
	10/19/94	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
	05/31/95	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)
	05/12/92	14,000	ND (1,200)	ND (1,200)	ND (1,200)	ND (4,200)	ND (1,200)	ND (1,000)	ND (1,200)	ND (12,000)	ND (12,000)	ND (1,200)	ND (1,200)
	08/11/92	18,000	ND (1,000)	ND (1,000)	ND (1,000)	ND (3,400)	ND (1,000)	ND (800)	ND (1,000)	ND (10,000)	ND (10,000)	ND (1,000)	ND (1,000)
(D)	10/23/92	16,000	ND (500)	ND (500)	ND (500)	ND (1,700)	ND (500)	ND (400)	ND (500)	ND (5,000)	ND (5,000)	ND (500)	ND (500)
	05/10/93	8,800	ND (310)	ND (310)	ND (310)	ND (1,100)	ND (310)	ND (250)	ND (310)	ND (3,100)	ND (3,100)	ND (310)	ND (310)
	11/08/93	9,400	ND (280)	ND (280)	ND (280)	ND (950)	ND (280)	ND (220)	ND (280)	ND (2,800)	ND (2,800)	ND (280)	ND (280)
	02/24/94	10,000	ND (500)	ND (500)	ND (500)	ND (1,700)	ND (500)	ND (400)	ND (500)	ND (5,000)	ND (5,000)	ND (500)	ND (500)
	02/24/94	7,800	ND (500)	ND (500)	ND (500)	ND (1,700)	ND (500)	ND (400)	ND (500)	ND (5,000)	ND (5,000)	ND (500)	ND (500)
(D)	05/10/94	8,400	ND (330)	ND (330)	ND (330)	ND (1,100)	ND (330)	ND (270)	ND (330)	ND (3,300)	ND (3,300)	ND (330)	ND (330)
	08/03/94	18,000	ND (1,000)	ND (1,000)	ND (1,000)	ND (3,400)	ND (1,000)	ND (800)	ND (1,000)	ND (10,000)	ND (10,000)	ND (1,000)	ND (1,000)
	10/19/94	14,000	ND (1,000)	ND (1,000)	ND (1,000)	ND (3,400)	ND (1,000)	ND (800)	ND (1,000)	ND (10,000)	ND (10,000)	ND (1,000)	ND (1,000)
	03/10/95	13,000	ND (500)	ND (500)	ND (500)	ND (1,700)	ND (500)	ND (400)	ND (500)	ND (5,000)	ND (5,000)	ND (500)	ND (500)
	06/20/95	3,300	ND (120)	ND (120)	ND (120)	ND (420)	ND (120)	ND (100)	ND (120)	ND (1,200)	ND (1,200)	ND (120)	ND (120)
U4-34	08/29/95	3,500	ND (100)	ND (100)	ND (100)	ND (340)	ND (100)	ND (80)	ND (100)	ND (1,000)	ND (1,000)	ND (100)	ND (100)

Appendix B. Concentrations of volatile organic compounds in water from wells and a seep in the area of Operable Unit 4, Hill Air Force Base, Utah—Continued

Well	Date sampled	TCE (µg/L)	1,1,2-DCE ¹ (µg/L)	Benzene (µg/L)	Chloroform (µg/L)	MC (µg/L)	1,2-DCA (µg/L)	1,1-DCE (µg/L)	PCE (µg/L)	Acetone (µg/L)	MEK (µg/L)	170 pHA	1,000 pMCL	Toluene (µg/L)	Xylenes (µg/L)
Water-quality standard		5.0 PMCL	2100 PMCL	5.0 PMCL	3100 MCL	NE	5.0 PMCL	7.0 pMCL	7.0 pMCL	NE			1,000 pMCL		
Upgradient from Canal—Continued															
U4-35	05/27/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
U4-36	04/22/92	7.5	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
	10/21/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
	04/15/93	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
	10/28/93	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
	05/24/94	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
	05/16/95	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
U4-37	05/14/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
U4-38	05/19/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
U4-39	04/21/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
U4-40	05/26/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
U4-43	05/06/92	440	ND (12)	ND (12)	ND (12)	ND (42)	ND (12)	ND (10)	ND (12)	ND (120)	ND (120)	ND (120)	ND (12)	ND (12)	ND (12)
	10/22/92	270	ND (12)	ND (12)	ND (12)	ND (42)	ND (12)	ND (10)	ND (12)	ND (120)	ND (120)	ND (120)	ND (12)	ND (12)	ND (12)
	04/20/93	260	ND (10)	ND (10)	ND (10)	ND (34)	ND (10)	ND (8)	ND (10)	ND (100)	ND (100)	ND (100)	ND (10)	ND (10)	ND (10)
	11/03/93	2,200	ND (72)	ND (72)	ND (72)	ND (240)	ND (72)	ND (57)	ND (72)	ND (720)	ND (720)	ND (720)	ND (72)	ND (72)	ND (72)
	02/24/94	1,300	ND (120)	ND (120)	ND (120)	ND (420)	ND (120)	ND (100)	ND (100)	ND (1,200)	ND (1,200)	ND (1,200)	ND (120)	ND (120)	ND (120)
	05/10/94	2,500	ND (100)	ND (100)	ND (100)	ND (340)	ND (100)	ND (80)	ND (100)	ND (1,000)	ND (1,000)	ND (1,000)	ND (100)	ND (100)	ND (100)
	03/09/95	1,400	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (500)	ND (500)	ND (50)	ND (50)	ND (50)
	06/06/95	1,600	ND (120)	ND (120)	ND (120)	ND (420)	ND (120)	ND (100)	ND (120)	ND (1,200)	ND (1,200)	ND (1,200)	ND (120)	ND (120)	ND (120)
	08/28/95	1,600	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (500)	ND (500)	ND (50)	ND (50)	ND (50)
U4-44 (D)	06/02/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
	06/02/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
Downgradient from Canal															
P2	10/23/89	ND (3)	ND (5)	ND (3)	ND (5)	ND (17)	ND (3)	ND (4)	ND (3)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
	05/18/93	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
	05/26/94	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
	05/30/95	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
P2A	11/02/89	ND (3)	ND (5)	ND (3)	ND (5)	22	ND (3)	ND (4)	ND (3)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
	05/28/93	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)
	05/31/95	ND (5)	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)

SECRET

Well	Date sampled	TCE (µg/L)	1,1,2-DCE ¹ (µg/L)		Benzene (µg/L)	Chloroform (µg/L)	MC (µg/L)	1,2-DCA (µg/L)		1,1-DCE (µg/L)	PCE (µg/L)	Acetone (µg/L)	MEK (µg/L)	Toluene (µg/L)	Xylenes (µg/L)		
			5.0 PMCL	2,100 PMCL				5.0 PMCL	NE							5.0 PMCL	7.0 PMCL
P3	05/03/89	13	ND	(5)	ND	(3)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	
	11/01/89	12	ND	(5)	ND	(3)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	
	04/04/91	12	ND	(5)	ND	(5)	ND	(17)	ND	(5)	ND	(4)	ND	(5)	ND	(5)	
	10/23/91	13	ND	(5)	ND	(5)	ND	(17)	ND	(5)	ND	(4)	ND	(5)	ND	(5)	
	07/16/92	8.8	ND	(5)	ND	(5)	ND	(17)	ND	(5)	ND	(4)	ND	(5)	ND	(5)	
	11/10/92	13	ND	(5)	ND	(5)	ND	(17)	ND	(5)	ND	(4)	ND	(5)	ND	(5)	
	04/09/93	11	ND	(5)	ND	(5)	ND	(17)	ND	(5)	ND	(4)	ND	(5)	ND	(5)	
	10/26/93	7.4	ND	(5)	ND	(5)	ND	(17)	ND	(5)	ND	(4)	ND	(5)	ND	(5)	
	06/02/94	7.1	ND	(5)	ND	(5)	ND	(17)	ND	(5)	ND	(4)	ND	(5)	ND	(5)	
	06/01/95	8.3	ND	(5)	ND	(5)	ND	(17)	ND	(5)	ND	(4)	ND	(5)	ND	(5)	
P4	05/24/89	ND	(3)	ND	(5)	ND	(3)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)
	10/17/89	42	ND	(5)	ND	(3)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	
	03/08/90	3.7	ND	(50)	ND	(0.70)	ND	(0.30)	ND	(0.50)	ND	(0.70)	ND	(0.40)	NA	ND	(2)
	04/23/91	ND	(5)	ND	(5)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	ND	(5)
	10/24/91	ND	(5)	ND	(5)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	ND	(5)
	07/21/92	ND	(5)	ND	(5)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	ND	(5)
	11/17/92	ND	(5)	ND	(5)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	ND	(5)
	04/19/93	ND	(5)	ND	(5)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	ND	(5)
	10/26/93	5.0	ND	(5)	ND	(5)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	(5)
	06/02/94	7.9	ND	(5)	ND	(5)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	(5)
P7	10/12/94	ND	(5)	ND	(5)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	ND	(5)
	06/01/95	7.5	ND	(5)	ND	(5)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	(5)
P8	05/02/89	ND	(3)	ND	(3)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	ND	(5)
	05/03/89	ND	(3)	ND	(3)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	ND	(5)
P10	10/19/89	79	ND	(5)	ND	(3)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	(5)
	10/20/89	72	12	ND	(3)	ND	(5)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)
P10A	03/04/94	110	6.4	ND	(5)	ND	(5)	ND	(17)	ND	(3)	ND	(4)	ND	(5)	ND	(5)
	06/12/95	64	ND	(5)	ND	(5)	ND	(17)	ND	(3)	ND	(4)	ND	(3)	ND	(5)	(5)

Appendix B. Concentrations of volatile organic compounds in water from wells and a seep in the area of Operable Unit 4, Hill Air Force Base, Utah--Continued

Well	Date sampled	TCE (µg/L)	Downgradient from Canal - Continued										MEK (µg/L)	Toluene (µg/L)	Xylenes (µg/L)
			5.0 PMCL	2,100 PMCL	5.0 PMCL	3 100 MCL	NE	5.0 PMCL	7.0 PMCL	1,1-DCE (µg/L)	PCE (µg/L)	Acetone (µg/L)			
Water-quality standard															
P11	10/24/89	2,800	ND (120)	ND (75)	ND (120)	ND (420)	ND (75)	ND (100)	ND (75)	ND (1,200)	ND (1,200)	ND (1,200)	ND (1,200)	ND (1,200)	ND (120)
	04/23/91	1,600	ND (100)	ND(100)	ND (100)	ND (340)	ND (100)	ND (80)	ND (100)	ND (1,000)	ND (1,000)	ND (1,000)	ND (1,000)	ND (100)	
	10/30/91	1,800	ND (1,000)	ND(1,000)	ND (1,000)	ND (3,400)	ND (1,000)	ND (800)	ND (1,000)	ND (10,000)	ND (10,000)	ND (1,000)	ND (1,000)	ND(1,000)	
	07/23/92	1,200	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (330)	ND (50)	ND (50)	ND (50)	
	07/23/92	1,200	ND (33)	ND (33)	ND (33)	ND (110)	ND (33)	ND (27)	ND (33)	ND (330)	ND (330)	ND (33)	ND (33)	ND (33)	
	11/18/92	1,200	ND (33)	ND (33)	ND (33)	ND (110)	ND (33)	ND (27)	ND (33)	ND (330)	ND (330)	ND (33)	ND (33)	ND (33)	
	05/14/93	1,000	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (500)	ND (50)	ND (50)	ND (50)	
(D)	10/27/93	760	ND (25)	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (25)	ND (25)	ND (25)	
	10/27/93	780	ND (25)	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (25)	ND (25)	ND (25)	
	03/02/94	780	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (500)	ND (50)	ND (50)	ND (50)	
	06/06/94	860	ND (25)	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (25)	ND (25)	ND (25)	
	06/06/94	870	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (500)	ND (50)	ND (50)	ND (50)	
	08/04/94	930	ND (25)	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (25)	ND (25)	ND (25)	
	08/04/94	930	ND (33)	ND (33)	ND (33)	ND (110)	ND (33)	ND (27)	ND (33)	ND (330)	ND (330)	ND (33)	ND (33)	ND (33)	
(D)	10/11/94	780	ND (33)	ND (33)	ND (33)	ND (110)	ND (33)	ND (27)	ND (33)	ND (330)	ND (330)	ND (33)	ND (33)	ND (33)	
	03/06/95	620	ND (25)	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (25)	ND (25)	ND (25)	
	06/19/95	610	ND (25)	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (25)	ND (25)	ND (25)	
	08/28/95	650	ND (25)	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (25)	ND (25)	ND (25)	
	06/15/89	380	ND (25)	ND (15)	ND (25)	ND (85)	ND (15)	ND (20)	ND (15)	ND (250)	ND (250)	ND (25)	ND (25)	ND (25)	
	06/15/89	380	17	ND (7.5)	ND (12)	ND (42)	ND (7.5)	ND (10)	ND (7.5)	ND (120)	ND (120)	ND (12)	ND (12)	ND (12)	
	10/27/89	290	12	ND (3)	ND (5)	ND (17)	ND (3)	ND (4)	ND (3)	84	ND (50)	ND (5)	ND (5)	ND (5)	
P22	10/26/89	290	ND (25)	ND (15)	ND (25)	ND (85)	ND (15)	ND (20)	ND (15)	ND (250)	ND (250)	ND (25)	ND (25)	ND (25)	
	03/01/94	4,900	ND (120)	ND(120)	ND (120)	ND (420)	ND (120)	ND (100)	ND (120)	ND (1,200)	ND (1,200)	ND (120)	ND (120)	ND (120)	
	03/09/95	3,200	ND (120)	ND(120)	ND (120)	ND (420)	ND (120)	ND (100)	ND (120)	ND (1,200)	ND (1,200)	ND (120)	ND (120)	ND (120)	
	06/26/95	3,400	ND (100)	ND(100)	ND (100)	ND (340)	ND (100)	ND (80)	ND (100)	ND (1,000)	ND (1,000)	ND (100)	ND (100)	ND (100)	
	06/26/95	3,500	ND (100)	ND(100)	ND (100)	ND (340)	ND (100)	ND (80)	ND (100)	ND (1,000)	ND (1,000)	ND (100)	ND (100)	ND (100)	
	08/30/95	2,000	ND (62)	ND (62)	ND (62)	ND (210)	ND (62)	ND (50)	ND (62)	ND (620)	ND (620)	ND (62)	ND (62)	ND (62)	
	03/08/90	1,300	ND (120)	ND (0.70)	ND (75)	ND (500)	ND (120)	ND (180)	ND (100)	NA	NA	ND (1)	ND (2)	ND (2)	
P25A	05/21/91	1,300	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (500)	ND (50)	ND (50)	ND (50)	
	11/14/91	1,300	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (500)	ND (50)	ND (50)	ND (50)	
	05/13/93	920	ND (33)	ND (33)	ND (33)	ND (110)	ND (33)	ND (27)	ND (33)	ND (330)	ND (330)	ND (33)	ND (33)	ND (33)	
	06/29/95	660	ND (25)	ND (25)	ND (25)	ND (85)	ND (25)	ND (20)	ND (25)	ND (250)	ND (250)	ND (25)	ND (25)	ND (25)	
	07/14/92	1,200	ND (80)	ND (80)	ND (80)	ND (270)	ND (80)	ND (64)	ND (80)	ND (800)	ND (800)	ND (80)	ND (80)	ND (80)	
	11/29/93	1,700	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (500)	ND (50)	ND (50)	ND (50)	
	05/25/94	1,700	ND (72)	ND (72)	ND (72)	ND (240)	ND (72)	ND (57)	ND (72)	ND (720)	ND (720)	ND (72)	ND (72)	ND (72)	
(D)	05/25/94	1,800	ND (72)	ND (72)	ND (72)	ND (240)	ND (72)	ND (57)	ND (72)	ND (720)	ND (720)	ND (72)	ND (72)	ND (72)	
	10/13/94	1,800	ND (120)	ND(120)	ND (120)	ND (420)	ND (120)	ND (100)	ND (120)	ND (1,200)	ND (1,200)	ND (120)	ND (120)	ND (120)	
	10/13/94	2,000	ND (120)	ND(120)	ND (120)	ND (420)	ND (120)	ND (100)	ND (120)	ND (1,200)	ND (1,200)	ND (120)	ND (120)	ND (120)	
	03/07/95	1,300	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (500)	ND (50)	ND (50)	ND (50)	
	06/20/95	1,500	ND (50)	ND (50)	ND (50)	ND (170)	ND (50)	ND (40)	ND (50)	ND (500)	ND (500)	ND (50)	ND (50)	ND (50)	
	08/29/95	1,200	ND (31)	ND (31)	ND (31)	ND (110)	ND (31)	ND (25)	ND (31)	ND (310)	ND (310)	ND (31)	ND (31)	ND (31)	
	03/08/94	6.7	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)	
U4-58	03/08/94	66	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)	
	03/08/94	14	ND (5)	ND (5)	ND (5)	ND (17)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)	

Appendix B. Concentrations of volatile organic compounds in water from wells and a seep in the area of Operable Unit 4, Hill Air Force Base, Utah-- Continued

Well	Date sampled	Downgradient from Canal--Continued															
		TCE (µg/L)	1,1,2-DCE ¹ (µg/L)	Benzene (µg/L)	Chloroform (µg/L)	MC (µg/L)	1,2-DCA (µg/L)	1,1-DCE (µg/L)	PCE (µg/L)	Acetone (µg/L)	MEK (µg/L)	170 pHA (µg/L)	1,000 pMCL (µg/L)	Toluene (µg/L)	Xylenes (µg/L)	1,000 pMCL (µg/L)	1,000 pMCL (µg/L)
COLBY	09/19/88	ND (0.1)	ND	ND (0.1)	ND (0.1)	ND (0.1)	ND (0.1)	ND (0.1)	ND (0.1)	NA	NA	NA	NA	NA	NA	NA	NA
	05/09/91	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	11/07/91	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	08/12/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	11/19/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	05/20/93	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	11/03/93	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	05/25/94	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	10/19/94	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
P1	05/22/89	ND (3)	ND (3)	ND (3)	ND (3)	ND (3)	ND (3)	ND (4)	ND (3)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	04/05/91	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	07/20/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	11/05/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	04/08/93	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	10/25/93	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	05/20/94	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	10/21/94	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	05/24/95	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
U4-41	07/06/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	10/27/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	04/20/93	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	10/22/93	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	05/11/94	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
U4-42	10/20/94	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	05/18/95	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	07/13/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	10/27/92	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)
	04/20/93	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (4)	ND (5)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)

¹Prior to October 1993, concentrations reported for trans-1,2-dichloroethylene are the sum of trans-1,2-dichloroethylene and cis-1,2-dichloroethylene

²The Water-Quality Standard for cis-1,2-dichloroethylene is 70 MCL

³The MCL is for total trihalomethanes, which include chloroform, bromoform, bromodichloromethane, and dibromochloromethane.

FINAL

APPENDIX C

TRACE METALS DETECTED IN GROUNDWATER (1986-1995)

Appendix C. Concentrations of selected trace elements in water from wells in the area of Operable Unit 4, Hill Air Force Base, Utah

[mg/L, milligrams per liter; Water-quality standards: MCL, maximum contaminant level was established by the U.S. Protection Agency's Safe Drinking Water Act; LHAL, Lifetime health advisory level; AL, action level; NE, not established; ND, not detected (detection limits are in parentheses); NA, not analyzed; D, blind duplicate analysis]

Well	Date sampled	Arsenic (mg/L)	Boron (mg/L)	Lead (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Iron (mg/L)	Manganese (mg/L)
Water quality standards		0.05 MCL	0.6 LHAL	0.015 AL	0.10 MCL	0.05 MCL	NE	NE
Upgradient from Canal								
LFIT-1	01/26/89	ND (0.003)	1.8	ND (0.002)	0.04	0.004	0.13	0.05
	11/07/91	.0071	1.3	ND (.0010)	.016	ND (.0030)	.18	.028
	07/23/92	.0040	NA	ND (.0050)	.042	ND (.0050)	ND(.040)	.045
	11/18/92	NA	1.5	NA	NA	NA	NA	NA
	04/22/93	NA	1.4	NA	NA	NA	NA	NA
	11/05/93	NA	1.8	NA	NA	NA	NA	NA
	06/03/94	NA	1.7	NA	NA	NA	NA	NA
	10/13/94	NA	1.4	NA	NA	NA	NA	NA
	06/02/95	NA	1.7	NA	NA	NA	NA	NA
	(D) 06/02/95	NA	1.7	NA	NA	NA	NA	NA
LF2T-1	01/25/89	ND (.3)	.11	ND (.2)	ND(.01)	ND (.4)	.35	.12
	04/01/91	ND (.30)	NA	ND (.20)	ND(.040)	ND (.40)	.37	.10
	10/16/91	NA	.14	NA	NA	NA	NA	NA
	07/10/92	NA	ND(.10)	NA	NA	NA	.30	NA
	11/03/92	NA	ND(.10)	NA	NA	NA	NA	NA
	04/02/93	NA	.10	NA	NA	NA	NA	NA
	10/29/93	NA	ND(.10)	NA	NA	NA	NA	NA
	05/23/94	NA	.10	NA	NA	NA	NA	NA
	10/18/94	NA	.13	NA	NA	NA	NA	NA
	05/26/95	NA	.14	NA	NA	NA	NA	NA
LF1GS1	12/18/91	.00094	.092	ND (.0010)	.0057	ND (.0020)	ND(.050)	.028
LF1GS3A	03/20/91	ND (.30)	NA	ND (.20)	ND(.040)	ND (.40)	ND(.040)	.022
	10/10/91	.040	.14	ND (.0010)	ND(.0010)	ND (.0020)	.14	.018
	07/09/92	.030	NA	ND (.0020)	.0015	ND (.0050)	.12	.015
	10/30/92	NA	.10	NA	NA	NA	NA	NA
	03/31/93	NA	.10	NA	NA	NA	NA	NA
	10/29/93	NA	.10	NA	NA	NA	NA	NA
	05/27/94	NA	.10	NA	NA	NA	NA	NA
	10/05/94	NA	.12	NA	NA	NA	NA	NA
	05/31/95	NA	.12	NA	NA	NA	NA	NA
	(D)							
LF1GS3B	02/01/89	ND (.003)	.41	ND (.004)	2.1	ND (.002)	11	.66
	11/06/91	ND (.0010)	.16	ND (.0010)	NA	.0031	ND(.050)	.015
	08/13/92	ND (.0010)	NA	.0012	.012	ND (.0050)	ND(.040)	.0020
	11/10/92	NA	.16	NA	NA	NA	NA	NA
	04/21/93	NA	1.7	NA	NA	NA	NA	NA
	04/21/93	NA	1.7	NA	NA	NA	NA	NA
	10/14/93	ND (.002)	NA	NA	ND(.020)	NA	.308	.0117
	01/18/94	ND (.002)	NA	NA	ND(.020)	NA	.154	ND (.010)
	06/08/94	NA	.62	NA	NA	NA	NA	NA
	10/05/94	NA	.41	NA	NA	NA	NA	NA
(D)	10/05/94	NA	.41	NA	NA	NA	NA	NA
	06/07/95	NA	1.2	NA	ND(.040)	NA	NA	NA

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04/04/91	ND	(.30)	NA	ND	(.20)	ND(.040)	ND	(.40)	.069	.20
10/25/91	NA		.11	NA		NA	NA		NA	NA
07/22/92	NA		.10	NA		NA	NA		.11	NA
11/13/92	NA		ND (.10)	NA		NA	NA		NA	NA
04/07/93	NA		ND (.10)	NA		NA	NA		NA	NA
11/04/93	NA		ND (.10)	NA		NA	NA		NA	NA
06/03/94	NA		.12	NA		NA	NA		NA	NA
10/17/94	NA		.12	NA		NA	NA		NA	NA
06/01/95	NA		.12	NA		NA	NA		NA	NA

UNPUBLISHED REPORT
Subject to revision

Appendix C. Concentrations of selected trace elements in water from wells in the area of Operable Unit 4, Hill Air Force Base, Utah—Continued

Well	Date sampled	Arsenic (mg/L)	Boron (mg/L)	Lead (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Iron (mg/L)	Manganese (mg/L)
Water quality standards		0.05 MCL	0.6 LHAL	0.015 AL	0.10 MCL	0.05 MCL	NE	NE
Upgradient from Canal—Continued								
LF1GS4B (D)	10/29/91	NA	0.22	NA	NA	NA	NA	NA
	07/24/92	NA	.25	NA	NA	NA	.058	NA
	11/17/92	NA	.24	NA	NA	NA	NA	NA
	11/17/92	NA	.24	NA	NA	NA	NA	NA
	05/07/93	NA	.25	NA	NA	NA	NA	NA
	11/04/93	NA	.36	NA	NA	NA	NA	NA
	11/04/93	NA	.35	NA	NA	NA	NA	NA
	06/03/94	NA	.39	NA	NA	NA	NA	NA
	10/17/94	NA	.39	NA	NA	NA	NA	NA
	06/05/95	NA	.33	NA	NA	NA	NA	NA
LF1GS6 (D)	01/30/89	ND (.003)	NA	ND (.004)	NA	.002	NA	NA
	11/13/91	.0014	1.5	ND (.0010)	.0039	.0066	ND(.050)	ND (.0010)
	11/13/91	.0016	1.5	ND (.0010)	.0037	.0057	ND(.050)	ND (.0010)
	07/07/92	.0011	NA	.008	.46	ND(.0050)	ND(.040)	ND (.010)
	10/28/92	NA	1.7	NA	NA	NA	NA	NA
	05/10/93	NA	2.0	NA	NA	NA	NA	NA
	05/10/93	NA	2.0	NA	NA	NA	NA	NA
P5A (D)	03/29/91	ND (.30)	NA	ND (.20)	ND(.040)	ND (.40)	ND(.040)	ND (.010)
	03/29/91	ND (.30)	NA	ND (.20)	ND(.040)	ND (.40)	.043	ND (.010)
	10/15/91	ND (.00050)	.16	ND (.0010)	.0034	ND (.0020)	ND(.040)	.0034
	07/02/92	NA	.13	NA	NA	NA	NA	NA
	04/01/93	NA	.11	NA	NA	NA	NA	NA
	06/01/94	NA	.13	NA	NA	NA	NA	NA
	05/17/95	NA	.19	NA	NA	NA	NA	NA
P5B (D)	04/02/91	ND (.30)	NA	ND (.20)	ND(.040)	ND (.40)	.61	.18
	10/28/91	NA	.15	NA	NA	NA	NA	NA
	10/28/91	NA	.16	NA	NA	NA	NA	NA
	07/15/92	NA	.15	NA	NA	NA	NA	NA
	04/07/93	NA	.13	NA	NA	NA	NA	NA
	06/01/94	NA	.17	NA	NA	NA	NA	NA
	05/17/95	NA	.22	NA	NA	NA	NA	NA
P17	03/21/91	ND (.30)	NA	ND (.20)	ND(.040)	ND (.40)	ND(.040)	.23
	10/17/91	.0069	.30	ND (.0010)	.0061	.0067	ND(.040)	.13
	07/08/92	.0044	NA	ND (.0020)	.034	ND (.0050)	ND(.040)	.14
P18	03/28/91	ND (.30)	NA	ND (.20)	1.7	ND (.40)	1.8	.95
	10/17/91	ND (.00050)	.35	ND (.0010)	.14	.053	.076	.042
	09/22/92	.00150	NA	ND (.0010)	1.2	ND (.0050)	1.9	.57
	06/07/94	NA	.33	NA	NA	NA	NA	NA
	06/05/95	NA	.36	NA	NA	NA	NA	NA
U4-33	05/06/92	.0051	NA	ND (.0050)	ND(.040)	ND (.40)	.045	.46
	10/22/92	NA	ND (.10)	NA	NA	NA	NA	NA
	04/16/93	NA	ND (.10)	NA	NA	NA	NA	NA
	11/03/93	NA	ND (.10)	NA	NA	NA	NA	NA
	05/10/94	NA	ND (.10)	NA	NA	NA	NA	NA
	10/19/94	NA	ND (.10)	NA	NA	NA	NA	NA
	05/31/95	NA	ND (.10)	NA	NA	NA	NA	NA

UNPUBLISHED REPORT
Subject to revision

U4-34

05/12/92	ND	(.0050)	NA	ND	(.0050)	ND(.040)	ND	(.40)	ND(.040)	.074
10/23/92	NA		1.1	ND	(.0050)	NA	NA		NA	NA
05/10/93	NA		.74	ND	(.0050)	NA	NA		NA	NA
11/08/93	NA		1.6	ND	(.0050)	NA	NA		NA	NA
05/10/94	NA		1.0	ND	(.05)	NA	NA		NA	NA
10/19/94	NA		1.5	NA		NA	NA		NA	NA
06/20/95	NA		1.6	ND	(.010)	NA	NA		NA	NA

UNPUBLISHED REPORT
Subject to revision

Appendix C. Concentrations of selected trace elements in water from wells in the area of Operable Unit 4, Hill Air Force Base, Utah—Continued

Well	Date sampled	Arsenic (mg/L)	Boron (mg/L)	Lead (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Iron (mg/L)	Manganese (mg/L)
Water quality standards		0.05 MCL	0.6 LHAL	0.015 AL	0.10 MCL	0.05 MCL	NE	NE

Upgradient from Canal—Continued

U4-35	05/27/92	0.065	NA	ND (.010)	ND(.040)	ND (.40)	0.13	0.12
	10/27/92	.037	.21	NA	NA	NA	NA	NA
	04/14/93	.039	.20	NA	NA	NA	NA	NA
	11/02/93	.048	.20	NA	NA	NA	NA	NA
	06/06/94	ND (.1)	.22	NA	NA	NA	NA	NA
	05/25/95	.058	.23	NA	NA	NA	NA	NA
U4-36	04/22/92	.0052	NA	ND (.0050)	ND(.040)	ND (.40)	.080	.42
	10/21/92	NA	.14	NA	NA	NA	NA	NA
	04/15/93	NA	.13	NA	NA	NA	NA	NA
	10/28/93	NA	.13	NA	NA	NA	NA	NA
	05/24/94	NA	.13	NA	NA	NA	NA	NA
	05/16/95	NA	.16	NA	NA	NA	NA	NA
U4-37 (D)	05/14/92	ND (.0050)	NA	ND (.010)	ND(.040)	ND (.40)	ND(.040)	.13
	07/01/93	ND (.0010)	.094	ND (.0010)	.030	ND (.0030)	NA	.078
	07/01/93	ND (.0010)	.10	.0020	.029	ND (.0030)	NA	.078
U4-38	05/19/92	ND (.0050)	NA	ND (.0050)	ND(.040)	ND (.40)	.24	.16
	06/30/93	.0015	.094	.015	.012	ND (.0030)	NA	.17
U4-39	04/21/92	.0055	NA	ND (.0050)	ND(.040)	ND (.40)	.23	.22
U4-40	05/26/92	ND (.0050)	NA	ND (.010)	ND(.040)	ND (.40)	.042	.064
	06/30/93	.0015	.10	.0030	.0095	ND (.0030)	NA	.022
U4-43	05/06/92	ND (.0050)	NA	ND (.0050)	ND(.040)	ND (.40)	ND(.040)	.17
	10/22/92	NA	2.3	ND (.050)	NA	NA	NA	NA
	04/20/93	NA	2.3	ND (.0050)	NA	NA	NA	NA
	11/03/93	NA	1.6	ND (.010)	NA	NA	NA	NA
	05/10/94	NA	1.5	ND (.010)	NA	NA	NA	NA
	06/06/95	NA	2.5	ND (.010)	NA	NA	NA	NA
U4-44 (D)	06/02/92	ND (.0050)	NA	ND (.0050)	ND(.040)	ND (.40)	ND(.040)	.017
	06/02/92	ND (.0050)	NA	ND (.0050)	ND(.040)	ND (.40)	.064	.018
	06/30/93	ND (.0010)	.083	.011	.026	ND (.0030)	NA	.0070
Davis-Weber Canal	10/09/91	.0021	.043	ND (.0010)	ND(.0010)	ND (.40)	ND(.040)ND	(.0010)

Downgradient from Canal

P2	05/18/93	NA	.15	NA	NA	NA	NA	NA
	05/26/94	NA	.16	NA	NA	NA	NA	NA
	05/30/95	NA	.19	NA	NA	NA	NA	NA
P2A	05/28/93	NA	.17	NA	NA	NA	NA	NA
	05/31/95	NA	.20	NA	NA	NA	NA	NA

Appendix C. Concentrations of selected trace elements in water from wells in the area of Operable Unit 4, Hill Air Force Base, Utah—Continued

Well	Date sampled	Arsenic (mg/L)	Boron (mg/L)	Lead (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Iron (mg/L)	Manganese (mg/L)
Water quality standards		0.05 MCL	0.6 LHAL	0.015 AL	0.10 MCL	0.05 MCL	NE	NE
Downgradient from Canal—Continued								
P3	04/04/91	ND (0.30)	NA	ND (0.20)	0.27	ND (0.40)	ND(0.040)	0.038
	10/23/91	NA	.12	NA	NA	NA	NA	NA
	07/16/92	NA	.11	NA	NA	NA	NA	NA
	11/10/92	NA	.11	NA	NA	NA	NA	NA
(D)	11/10/92	NA	.10	NA	NA	NA	NA	NA
	04/09/93	NA	.10	NA	NA	NA	NA	NA
	10/26/93	NA	.11	NA	NA	NA	NA	NA
	06/02/94	NA	.12	NA	NA	NA	NA	NA
	06/01/95	NA	.12	NA	.13	NA	NA	NA
P4	10/24/91	NA	.22	NA	NA	NA	NA	NA
	07/21/92	NA	.18	NA	NA	NA	.063	NA
	11/17/92	NA	.22	NA	NA	NA	NA	NA
	04/19/93	NA	.17	NA	NA	NA	NA	NA
	10/26/93	NA	.21	NA	NA	NA	NA	NA
	06/02/94	NA	.22	NA	NA	NA	NA	NA
	10/12/94	NA	.31	NA	NA	NA	NA	NA
	06/01/95	NA	.23	NA	NA	NA	NA	NA
P11	10/30/91	.0036	.33	ND (.0010)	.074	.0030	ND(.040)	.022
	07/23/92	.0031	NA	ND (.0020)	.090	ND (.0050)	ND(.040)	.013
(D)	07/23/92	.0030	NA	ND (.0020)	.089	ND (.0050)	ND(.040)	.012
	11/18/92	NA	.31	NA	NA	NA	NA	NA
	05/14/93	NA	.29	NA	NA	NA	NA	NA
	10/27/93	NA	.30	NA	NA	NA	NA	NA
(D)	10/27/93	NA	.31	NA	NA	NA	NA	NA
	06/06/94	NA	.30	NA	NA	NA	NA	NA
(D)	06/06/94	NA	.30	NA	NA	NA	NA	NA
	10/11/94	NA	.37	NA	NA	NA	NA	NA
	06/19/95	NA	.37	NA	NA	NA	NA	NA
P25A	11/14/91	.0041	.21	ND (.0010)	.0029	ND (.0030)	.050	.0017
	05/13/93	NA	.16	NA	NA	NA	NA	NA
U4-45	07/14/92	ND (.0050)	NA	ND (.010)	ND(.040)	ND (.40)	.063	.027
	11/29/93	NA	.11	NA	NA	NA	NA	NA
	05/25/94	NA	.12	NA	NA	NA	NA	NA
(D)	05/25/94	NA	.12	NA	NA	NA	NA	NA
	10/13/94	NA	.18	NA	NA	NA	NA	NA
(D)	10/13/94	NA	.18	NA	NA	NA	NA	NA
	06/20/95	NA	.15	NA	NA	NA	NA	NA
COLBY	11/07/91	.0016	.067	ND (.0010)	.0023	ND (.0030)	3.4	.050
	08/12/92	NA	ND(.10)	NA	NA	NA	.55	NA
	11/19/92	NA	ND(.10)	NA	NA	NA	NA	NA
	05/20/93	NA	ND(.10)	NA	NA	NA	NA	NA
	11/03/93	NA	ND(.10)	NA	NA	NA	NA	NA
	05/25/94	NA	ND(.10)	NA	NA	NA	NA	NA
	10/19/94	NA	ND(.10)	NA	NA	NA	NA	NA

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Appendix C. Concentrations of selected trace elements in water from wells in the area of Operable Unit 4, Hill Air Force Base, Utah—Continued

Well	Date sampled	Arsenic (mg/L)	Boron (mg/L)	Lead (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Iron (mg/L)	Manganese (mg/L)
Water quality standards		0.05 MCL	0.6 LHAL	0.015 AL	0.10 MCL	0.05 MCL	NE	NE
Flood Plain								
PI	04/05/91	ND (0.30)	NA	ND (0.20)	ND(0.040)	ND (0.40)	0.80	0.083
	11/12/91	NA	.33	ND (.0010)	.0022	ND (.0030)	.67	.076
	07/20/92	.035	NA	ND (.0020)	ND(.0010)	ND (.0050)	.80	.078
	11/05/92	NA	.3	NA	NA	NA	NA	NA
	04/08/93	NA	.31	NA	NA	NA	NA	NA
	10/25/93	NA	.35	NA	NA	NA	NA	NA
	05/20/94	NA	.32	NA	NA	NA	NA	NA
	10/21/94	NA	.33	NA	NA	NA	NA	NA
	05/24/95	NA	.32	NA	NA	NA	NA	NA
U4-41	07/06/92	.039	NA	ND (.010)	ND(.040)	ND (.40)	.45	.063
	10/27/92	.052	.33	NA	NA	NA	NA	NA
	04/20/93	.053	.32	NA	NA	NA	NA	NA
	10/22/93	.33	.55	NA	NA	NA	NA	NA
	05/11/94	ND (.1)	.34	NA	NA	NA	NA	NA
	10/20/94	.056	.35	NA	NA	NA	NA	NA
	05/18/95	.053	.34	NA	NA	NA	NA	NA
U4-42	07/13/92	.094	NA	ND (.0050)	ND(.040)	ND (.40)	.34	.079
	10/27/92	.098	.56	NA	NA	NA	NA	NA
	04/20/93	.090	.51	NA	NA	NA	NA	NA
	10/22/93	.19	.33	NA	NA	NA	NA	NA
	05/11/94	.11	.55	NA	NA	NA	NA	NA
	10/20/94	.11	.57	NA	NA	NA	NA	NA
	05/18/95	.10	.54	NA	NA	NA	NA	NA

FINAL

APPENDIX D

**DISSOLVED INORGANIC CONSTITUENTS DETECTED IN
GROUNDWATER (1986-1995)**

Appendix D. Concentrations of selected dissolved inorganic constituents, alkalinity, and pH in water from wells and a seep in the area of Operable Unit 4, Hill Air Force Base, Utah

[mg/L, milligrams per liter; Water-quality standards; NE, not established; MCL, maximum contaminant level established by the U.S. Environmental Protection Agency's Safe Drinking Water Act, except for solids and sulfate, which are established by the State of Utah Department of Environmental Quality; ND, not detected; D, blind duplicate analysis; NA, not analyzed; **, samples collected by Montgomery Watson, Incorporated]

Well or seep	Date sampled	Silica (mg/L as SiO ₂)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Total alkalinity (mg/L as HCO ₃)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)	Fluoride (mg/L)	pH, field (standard units)	Solids, dissolved, sum of constituents ¹ (mg/L)
Water-quality standards	NE	NE	NE	NE	NE	NE	NE	NE	1,000 MCL	10 MCL	4.0 MCL	NE	2,000 MCL
Upgradient from Canal													
✓ LFIT-1	01/26/89	30	87	50	50	10	411	63	100	3.0	ND	7.6	
	05/18/89	28	119	41	64	ND	357	81	136	3.9	.8	7.7	
	04/19/91	28.1	95.7	43.3	49.0	6.9	394	65.0	97.8	2.8	.54	7.6	596
(D)	04/19/91	27.9	95.3	43.1	49.1	6.9	391	65.1	98.2	2.8	.54	7.6	594
	11/07/91	29.9	83.1	46.3	46.3	9.0	394	59.6	77.2	1.9	ND	7.6	
	✓ 07/23/92	26.2	80.2	38.7	45.6	6.9	380	67.2	74.7	2.2	.88	7.5	540
	11/18/92	28.2	89.3	41.6	52.6	6.7	384	77.5	68.9	1.3	ND	7.5	
	04/22/93	23.8	111	40.0	102	ND	402	195	79.6	1.9	.92	7.6	
	11/05/93	25.0	91.5	35.4	62.9	ND	381	80.9	81.2	1.9	.76	7.6	
	06/03/94	25.8	101	40.2	69.9	5.4	378	101	63.5	ND	ND	7.3	
	10/13/94	29.2	87.6	43.0	55.9	7.5	495	74.2	51.5	1.4	ND	7.3	
	06/02/95	23.7	110	38.7	88.3	ND	368	162	76.2	1.9	ND	7.4	
(D)	06/02/95	23.2	107	37.7	85.7	ND	365	161	77.9	1.9	ND	7.4	
✓ LF2T-1	01/25/89	22	72	49	49	11	222	77	24	ND	ND	7.3	
	04/01/91	NA	71.4	46.8	45.8	11.0	423	37.5	19.1	ND	.61	7.4	
	10/16/91	24.0	72.0	48.1	46.3	11.7	439	73.5	19.4	ND	ND	7.4	
	07/10/92	18.6	63.1	41.8	41.9	9.9	424	73.4	20.0	ND	.98	7.2	
	11/03/92	22.0	71.4	45.8	44.4	10.6	415	72.0	20.8	ND	ND	7.3	
	04/02/93	21.8	74.1	48.9	48.0	11.4	433	76.5	22.4	ND	ND	7.3	
	10/29/93	22.4	74.4	48.0	46.7	10.5	389	39.6	13.2	ND	.60	7.4	
	05/23/94	21.9	71.0	46.5	43.2	9.9	417	70.3	21.6	ND	ND	7.3	
	10/18/94	23.3	74.3	48.9	48.5	11.4	396	68.6	21.8	ND	ND	NA	
	05/26/95	22.3	77.9	50.5	50.6	12.0	441	73.9	24.6	ND	.52	7.1	
LF1GS1	01/24/89	7.6	104	33	42	ND	375	46	91	ND	ND	7.4	
	12/18/91	15.0	105	32.1	42.3	ND	379	49.9	95.2	.54	.89	7.4	
✓ LF1GS3A	02/01/89	15	43	53	31	13	362	38	19	ND	ND	7.5	
	07/07/89	35	42	54	34	15	408	42	13	ND	ND	7.6	
	03/20/91	NA	40.4	51.4	32.1	13.9	417	41.6	12.6	ND	ND	7.7	
	10/10/91	31.7	40.7	52.3	32.8	14.3	422	41.0	12.0	ND	ND	7.7	
	✓ 07/09/92	23.5	31.5	40.8	25.4	11.1	240	41.0	13.4	ND	.80	7.6	
	10/30/92	32.0	41.1	52.1	32.4	14.3	407	42.0	14.1	.53	ND	7.7	
	03/31/93	31.5	41.1	52.5	33.3	14.8	404	40.6	13.4	ND	ND	7.7	
	10/29/93	32.9	42.7	52.9	33.8	14.0	414	71.5	21.1	ND	.78	7.7	
	05/27/94	31.0	40.1	49.0	29.9	12.4	392	39.5	14.5	ND	ND	7.6	
	10/05/94	32.3	40.1	52.7	33.7	14.5	422	39.7	14.7	ND	.51	7.5	
	05/31/95	30.1	39.0	48.9	30.1	13.6	379	39.2	15.1	ND	ND	7.5	

Well or seep	Date sampled	Silica (mg/L as SiO ₂)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Total alkalinity (mg/L as HCO ₃)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)	Fluoride (mg/L)	pH, field (standard units)	Solids, dissolved, sum of constituents ¹ (mg/L)
Water-quality standards	NE	NE	NE	NE	NE	NE	NE	NE	1,000 MCL	10 MCL	4.0 MCL	NE	2,000 MCL

LFIGS3B	02/01/89	23	213	71	100	6	314	160	504	0.8	0.6	6.9	812
	05/10/89	23	288	78	151	ND	431	172	744	.90	1.6	7.7	
	10/19/89	22	140	53	66	7	385	102	211	ND	.7	7.2	
	04/10/91	21.9	141	50.9	63.6	6.1	417	104	226	ND	.84	7.5	
	11/06/91	23.0	104	41.7	51.8	6.5	409	71.0	94.0	ND	ND	7.3	
	08/13/92	19.4	110	39.1	52.9	5.5	401	87.6	148	ND	ND	7.4	
	11/10/92	21.3	97.7	37.9	50.1	6.1	380	76.6	104	ND	ND	7.4	
	04/21/93	23.7	573	199	516	ND	358	1,100	1,760	ND	4.2	7.0	
(D)	04/21/93	23.8	514	200	521	ND	359	1,210	1,890	ND	3.9	7.0	
	** 10/14/93	NA	176	63.3	118	5.82	452	170	296	.29	ND		
	** 01/18/94	NA	159	57.1	959	4.99	440	137	283	.29	ND		
	06/08/94	22.2	259	79.1	153	ND	383	195	542	ND	ND	7.4	
	10/05/94	22.1	156	56.1	103	5.6	428	132	289	ND	ND	7.4	
(D)	10/05/94	22.2	156	55.7	102	5.6	433	135	295	ND	ND	7.4	
	06/07/95	24.8	330	97.4	242	ND	395	204	945	ND	ND	7.2	
LFIGS4A	01/31/89	12	70	42	40	9	404	63	51	ND	ND	7.6	
	04/21/89	24	67	43	56	9	370	61	50	ND	ND	7.5	
	04/04/91	NA	59.8	40.5	50.4	9.3	370	67.2	25.8	ND	.64	7.7	
	10/25/91	22.3	61.7	41.6	51.7	9.3	492	65.4	22.5	ND	ND	7.5	
	07/22/92	19.2	56.3	37.8	51.8	8.5	387	66.4	21.6	ND	.60	7.6	
	11/13/92	22.4	59.5	39.1	52.0	7.9	374	66.5	21.6	ND	ND	7.6	
	04/07/93	19.2	61.2	38.8	59.5	8.4	379	76.9	38.8	.57	ND	7.4	
	11/04/93	20.8	59.3	37.5	55.2	8.2	372	71.7	32.8	.54	.79	7.5	475
	06/03/94	21.9	66.8	42.0	61.3	9.0	368	75.0	31.6	ND	ND	7.4	
	10/17/94	23.5	65.7	42.1	59.4	9.1	346	73.1	27.5	ND	ND	7.3	
	06/01/95	19.9	69.3	40.3	65.4	8.6	373	92.1	42.1	ND	.64	7.4	
LFIGS4B	04/09/91	23.4	101	49.3	68.2	ND	426	89.9	114	4.2	.72	7.3	
	10/29/91	24.5	104	49.5	70.0	5.2	431	91.8	111	4.0	ND	7.3	
	07/24/92	23.0	97.9	48.4	67.5	ND	426	98.8	116	3.2	1.1	7.3	
(D)	11/17/92	25.1	104	50.1	68.6	ND	411	98.3	117	2.9	ND	7.4	
	11/17/92	24.9	104	49.8	68.0	5.2	401	215	103	1.9	ND	7.4	
	05/07/93	23.6	109	54.7	70.0	5.0	435	106	117	3.2	.83	7.3	
	11/04/93	24.1	131	63.5	76.8	5.7	413	203	125	2.3	1.2	7.4	847
(D)	11/04/93	23.8	129	62.7	76.4	5.6	414	201	125	2.4	1.2	7.4	
	06/03/94	24.9	145	71.9	86.1	6.1	417	199	107	2.1	ND	7.7	
	10/17/94	26.6	142	68.									

Appendix D. Concentrations of selected dissolved inorganic constituents, alkalinity, and pH in water from wells and a seep in the area of Operable Unit 4, Hill Air Force Base, Utah—Continued

Well or seep	Date sampled	Silica (mg/L as SiO ₂)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Total alkalinity (mg/L as HCO ₃)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)	Fluoride (mg/L)	pH, field (standard units)	Solids, dissolved, sum of constituents ¹ (mg/L)
Water-quality standards	NE	NE	NE	NE	NE	NE	NE	NE	1,000 MCL	10 MCL	4.0 MCL	NE	2,000 MCL
Upgradient from Canal—Continued													
✓ PSA	05/23/89	25	86	70	74	7	510	132	40	1.1	0.9	7.5	695
	03/29/91	24.3	90.1	75.0	71.9	9.2	601	147	41.8	1.5	.95	7.5	767
(D)	03/29/91	24.6	91.7	76.3	73.1	9.5	581	149	41.4	1.5	.95	7.5	764
	10/15/91	26.4	90.8	77.3	75.1	8.1	606	147	36.2	2.3	ND	7.3	
	07/02/92	22.6	81.5	64.4	65.6	7.6	508	121	39.3	1.7	1.2	7.3	665
	04/01/93	23.0	90.2	69.7	70.3	8.2	531	137	39.6	1.6	ND	7.3	
	06/01/94	23.5	100	74.9	82.6	7.9	549	149	33.3	.77	ND	7.4	
	05/17/95	24.9	123	93.9	97.0	8.9	614	203	47.2	1.3	ND	7.1	
✓ P5B	06/15/89	25	55	60	68	16	456	123	26	ND	.6	7.5	
	10/18/89	21	56	63	67	16	439	107	20	ND	ND	7.6	
	04/02/91	NA	56.8	64.7	69.8	17.1	819	101	14.8	ND	.87	7.7	
	10/28/91	21.8	54.0	62.6	68.6	16.4	481	109	17.2	ND	ND	7.6	
(D)	10/28/91	22.3	54.5	63.7	70.0	16.8	482	109	16.8	ND	ND	7.6	
	07/15/92	21.3	49.6	59.0	64.6	15.9	465	103	15.5	ND	1.2	7.4	
	04/07/93	20.0	51.3	61.6	65.7	17.1	471	98.4	16.9	ND	ND	7.5	
	06/01/94	24.3	54.1	66.5	70.2	18.2	485	97.9	13.2	ND	ND	7.5	
	05/17/95	25.1	55.5	69.0	73.4	19.1	491	93.7	13.5	ND	.74	7.3	
✓ P17	03/21/91	NA	61.6	74.7	138	22.4	502	221	88.4	ND	1.3	7.6	
	10/17/91	19.2	63.0	77.8	148	24.2	500	226	84.9	ND	1.4	7.4	
	07/08/92	14.7	51.2	66.4	119	19.3	456	229	87.0	.85	1.5	7.6	820
✓ P18	03/28/91	NA	106	142	258	28.3	463	577	269	.83	2.1	7.3	
	10/17/91	25.0	107	151	272	26.7	573	547	283	.88	2.6	7.4	1,705
	09/22/92	18.1	102	121	246	25.4	515	520	255	.85	1.6	7.2	1,550
	06/07/94	20.9	103	139	260	29.0	540	468	230	1.2	ND	7.4	
	06/05/95	23.1	178	87.7	90.2	6.9	430	367	110	1.7	ND	7.4	
✓ U4-33	05/06/92	NA	68.8	32.3	29.8	8.0	359	41.0	28.2	ND	.76	7.2	
	10/22/92	25.9	59.8	36.6	30.6	8.8	365	41.1	19.3	ND	ND	7.6	
	04/16/93	29.0	64.5	40.2	32.0	8.5	346	38.9	18.9	ND	ND	7.6	
	11/03/93	21.3	78.2	27.9	29.0	6.5	323	53.3	37.9	1.2	.63	7.4	422
	05/10/94	20.6	82.4	29.1	29.4	5.1	303	62.8	40.9	ND	ND	7.3	
	10/19/94	26.4	78.9	34.6	32.0	7.3	311	70.8	29.7	ND	ND	7.4	
	05/31/95	20.9	80.8	28.6	29.5	5.6	335	55.0	34.5	ND	ND	7.3	
✓ U4-34	05/12/92	NA	108	31.7	170	ND	482	62.9	184	.46	1.1	7.2	
	10/23/92	18.8	93.9	26.6	172	ND	493	70.3	201	.86	ND	7.4	
	05/10/93	16.0	83.5	26.0	123	ND	481	47.4	108	.54	.72	7.3	
	11/08/93	17.6	92.3	25.5	219	ND	453	64.2	268	.56	1.0	7.4	
	05/10/94	18.4	85.6	25.4	156	ND	458	61.5	169	.57	ND	7.3	
	10/19/94	19.1	94.7	26.7	218	ND	454	70.3	285	ND	ND	7.4	
	06/20/95	18.9	103	33.3	201	7.3	468	63.2	449	.92	ND	7.4	
U4-35	05/27/92	NA	38.8	47.3	41.0	17.7	429	50.5	4.6	ND	.86	7.5	
	10/27/92	28.2	40.2	50.7	41.1	17.5	NA	NA	NA	NA	NA	7.6	
	04/14/93	28.1	40.1	54.0	44.4	17.6	NA	NA	NA	NA	NA	7.6	
	11/02/93	26.9	37.4	49.1	41.9	17.8	NA	NA	NA	NA	NA	7.7	
	06/06/94	29.0	41.7	54.2	43.6	17.4	NA	NA	NA	NA	NA	7.6	
	05/25/95	29.1	42.1	54.7	44.3	18.0	NA	NA	NA	NA	NA	7.5	

Appendix D. Concentrations of selected dissolved inorganic constituents, alkalinity, and pH in water from wells and a seep in the area of Operable Unit 4, Hill Air Force Base, Utah—Continued

Well or seep	Date sampled	Silica (mg/L as SiO ₂)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Total alkalinity (mg/L as HCO ₃)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)	Fluoride (mg/L)	pH, field (standard units)	Solids, dissolved, sum of constituents ¹ (mg/L)
Water-quality standards	NE	NE	NE	NE	NE	NE	NE	NE	1,000 MCL	10 MCL	4.0 MCL	NE	2,000 MCL
Upgradient from Canal—Continued													
✓ U4-36	04/22/92	NA	68.4	55.6	69.9	11.5	465	85.7	65.5	ND	1.1	7.4	
	10/21/92	20.5	67.3	57.1	69.8	11.7	458	91.8	63.2	ND	.66	7.4	
	04/15/93	23.3	70.6	63.0	77.2	12.2	468	96.0	65.1	ND	.86	7.4	
	10/28/93	22.2	72.5	60.1	66.4	11.4	453	93.1	61.7	ND	1.0	7.4	
	05/24/94	22.1	69.6	60.3	64.9	10.8	451	97.6	62.7	ND	ND	7.1	
	05/16/95	21.4	68.1	58.8	71.4	12.6	469	98.4	65.0	ND	.78	7.1	
✓ U4-37	05/14/92	NA	99.3	34.4	43.1	ND	364	90.9	42.4	3.9	1.1	7.2	
U4-38	05/19/92	NA	74.6	20.6	32.6	ND	346	28.4	57.4	.82	.75	7.3	
U4-39	04/21/92	NA	80.4	25.3	34.1	5.4	359	46.0	21.7	ND	.86	7.2	
U4-40	05/26/92	NA	64.5	18.3	32.3	ND	268	24.0	53.4	1.4	.83	7.5	
✓ U4-43	05/06/92	NA	124	42.7	48.4	ND	374	71.9	176	² 6.0	1.0	7.2	
	10/22/92	17.9	113	38.1	42.7	ND	358	69.9	136	5.7	ND	7.4	
	04/20/93	18.7	117	40.2	43.6	ND	378	69.7	135	5.2	.72	7.2	
	11/03/93	17.9	166	61.8	57.0	5.3	339	78.6	400	6.5	1.3	7.4	986
	05/10/94	18.0	176	65.4	56.4	ND	322	88.7	391	6.2	ND	7.4	
	06/06/95	19.5	182	71.0	66.9	5.3	381	74.2	366	6.8	ND	7.1	
U4-44	06/02/92	NA	92.6	30.1	40.5	ND	341	83.0	42.0	2.2	.84	7.3	
(D)	06/02/92	NA	91.4	29.6	39.8	ND	346	83.3	41.9	2.3	.84	7.3	
Downgradient from Canal													
Davis-Weber Canal	08/03/88	NA	61	18	19	NA	254	30	32	.17	NA		
	10/10/89	4.8	62	19	23	ND	222	31	32	ND	ND		
	10/09/91	3.3	59.8	17.2	20.3	ND	210	31.2	28.7	ND	ND	8.7	
P2	10/23/89	26	80	88	79	18	584	144	67	ND	1.0		
	05/18/93	20.2	82.6	94.9	82.2	16.7	553	148	107	.54	1.0	7.5	
	05/26/94	24	83.1	94.5	84.9	16.0	534	169	101	.60	ND	7.4	
	05/30/95	21.5	90.5	100	92.0	17.6	518	223	117	.92	ND	7.4	
P2A	11/02/89	25	79	82	88	16	574	130	68	ND	.9		
	05/28/93	25.5	90.4	95.2	101	16.7	541	166	97.2	.78	1.1	7.4	
	05/31/95	22.3	102	107	103	16.8	528	283	120	.62	ND	7.3	
P3	05/03/89	24	80	66	73	7	441	139	71	ND	ND	7.6	
	11/01/89	24	80	68	72	7	453	132	76	ND	.7	7.4	
	04/04/91	NA	69.9	59.2	74.9	6.3	470	94.7	69.6	ND	.69	7.5	
	10/23/91	25.4	68.9	57.5	71.2	6.4	443	93.0	67.1	ND	ND	7.5	
	07/16/92	22.8	64.9	53.2	64.1	5.6	446	96.6	67.0	.53	1.0	7.4	601
	11/10/92	24.8	64.7	52.8	70.0	6.0	441	79.9	60.9	ND	ND	7.5	
(D)	11/10/92	24.8	64.8	53.0	70.4	6.0	440	79.8	60.7	ND	ND	7.5	
	04/09/93	22.9	63.9	54.5	69.3	6.1	453	80.2	62.4	ND	ND	7.4	
	10/26/93	24.9	65.8	52.9	63.7	5.8	411	77.2	57.8	ND	.80	7.6	
	06/02/94	24.4	70.7	57.7	73.5	6.2	426	86.5	60.1	ND	ND	7.8	
	06/01/95	21.7	64.4	51.9	61.0	5.7	440	78.6	52.2	ND	.58	7.5	

Appendix D. Concentrations of selected dissolved inorganic constituents, alkalinity, and pH in water from wells and a seep in the area of Operable Unit 4, Hill Air Force Base, Utah—Continued

Well or seep	Date sampled	Silica (mg/L as SiO ₂)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Total alkalinity (mg/L as HCO ₃)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)	Fluoride (mg/L)	pH, field (standard units)	Solids, dissolved, sum of constituents ¹ (mg/L)
Water-quality standards	NE	NE	NE	NE	NE	NE	NE	NE	1,000 MCL	10 MCL	4.0 MCL	NE	2,000 MCL
Downgradient from Canal—Continued													
P4	05/24/89	25	80	99	83	15	547	157	87	ND	0.9	7.6	
	10/17/89	22	64	95	94	16	564	148	72	ND	1.0	7.2	
	04/23/91	21.4	98.8	134	92.3	13.7	623	237	149	ND	1.5	7.8	
	10/24/91	22.9	82.6	117	90.9	14.7	621	199	119	ND	1.4	7.5	
	07/21/92	19.5	81.1	117	97.7	14.2	655	203	122	ND	1.7	7.7	
	11/17/92	21.1	69.4	107	109	16.0	590	179	110	ND	ND	7.6	
	04/19/93	20.9	78.4	120	108	14.9	643	176	125	ND	1.3	7.4	
	10/26/93	20.8	67.4	97.4	98.6	14.4	576	145	88.5	ND	1.2	7.7	
	06/02/94	20.3	66.6	100	98.9	14.9	582	142	85.8	ND	ND	7.4	
	10/12/94	21.5	56.9	96.9	127	20.8	576	140	76.4	ND	ND	7.8	
	06/01/95	19.0	68.4	99.6	89.7	14.2	624	132	94.6	ND	ND	7.4	
P7	05/02/89	21	41	44	83	19	452	66	9.5	ND	ND	8.3	
P8	05/03/89	33	41	58	71	17	469	90	.8	ND	ND	7.9	
P10	10/19/89	18	64	73	50	14	378	110	84	ND	1.0	7.7	
P10A	10/20/89	18	70	46	66	8	397	57	51	.6	1.0	7.9	
	06/12/95	19.1	121	98.0	79.3	8.7	473	262	127	.6	ND	7.4	
P11	10/24/89	26	89	86	114	13	524	140	150	2.4	.9	7.7	892
	04/23/91	23.7	64.5	65.6	92.6	10.0	486	91.2	97.0	1.3	.78	7.5	694
	10/30/91	26.2	71.3	74.4	102	11.5	502	115	103	1.9	.95	7.5	762
	07/23/92	23.0	57.9	59.7	86.1	10.0	469	95.0	81.1	1.4	1.1	7.4	655
	11/18/92	24.7	61.9	62.5	86.3	10.3	461	99.8	77.4	1.1	ND	7.5	
	05/14/93	20.9	74.0	79.6	95.8	10.9	469	168	95.4	1.6	.98	7.5	787
	10/27/93	25.5	72.6	72.3	99.0	11.2	478	128	73.7	.88	.96	7.4	726
	06/06/94	23.8	71.3	72.8	102	11.5	497	129	72.6	.64	ND	7.7	
	10/11/94	28.1	74.5	79.4	116	15.3	495	128	74.9	.68	ND	7.3	
	06/19/95	24.9	84.9	88.1	115	14.0	549	163	92.3	.55	ND	7.4	
P21	06/15/89	15	52	29	77	ND	323	68	73	1.1	ND	7.9	
	10/27/89	18	70	38	80	6	333	78	82	NA	.5	7.8	
P22	10/26/89	20	53	56	77	11	403	85	67	1.1	.8	7.9	
	06/26/95	20.8	77.8	82.6	136	11.6	538	141	164	2.4	ND	7.5	
(D)	06/26/95	20.7	77.2	81.9	135	11.7	546	141	164	2.3	ND	7.5	
✓ P25A	03/08/90	27.0	79.2	122	92.5	20.4	731	178	114	1.0	1.3	7.5	1,004
	05/21/91	27.2	68.6	114	94.8	20.1	697	158	134	.99	1.4	7.6	977
	✓ 11/14/91	29.4	66.7	115	100	22.1	686	159	140	.78	1.4	7.5	980
	05/13/93	22.5	126	188	133	20.1	647	462	195	3.1	2.2	7.3	1,486
	06/29/95	NA	NA	NA	NA	NA	614	227	181	.91	ND	NA	
U4-45	07/14/92	NA	72.2	84.3	81.8	1.8	534	113	132	.83	1.3	7.3	
	11/29/93	22.4	70.2	77.4	83.3	9.7	534	111	136	1.0	.90	7.4	782
	05/25/94	22.5	73.4	81.2	92.2	9.6	495	116	137	1.1	ND	7.4	
(D)	05/25/94	22.6	73.7	82.6	90.2	10.1	496	118	137	1.1	ND	7.4	
	10/13/94	23.9	78.1	84.3	102	11.1	498	109	137	.90	ND	7.5	
(D)	10/13/94	24.0	77.6	84.3	101	11.0	500	108	136	1.1	ND	7.5	
	06/20/95	21.6	67.0	77.3	88.2	10.7	502	101	122	1.1	ND	7.4	

S9	06/18/92	NA	100	48	89	5	NA	NA	NA	NA	NA	7.5
(D)	06/18/92	NA	100	48	88	5	NA	NA	NA	NA	NA	NA

Appendix D. Concentrations of selected dissolved inorganic constituents, alkalinity, and pH in water from wells and a seep in the area of Operable Unit 4, Hill Air Force Base, Utah—Continued

Well or seep	Date sampled	Silica (mg/L as SiO ₂)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Total alkalinity (mg/L as HCO ₃)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (mg/L as N)	Fluoride (mg/L)	pH, field (standard units)	Solids, dissolved, sum of constituents ¹ (mg/L)
Water-quality standards	NE	NE	NE	NE	NE	NE	NE	NE	1,000 MCL	10 MCL	4.0 MCL	NE	2,000 MCL
COLBY	05/09/91	13.1	64.9	17.3	29.0	ND	295	18.0	16.2	ND	ND	7.9	
	11/07/91	13.3	67.0	17.2	28.4	ND	301	18.3	17.8	ND	ND	7.8	
	08/12/92	11.5	64.1	15.8	22.9	ND	290	19.8	22.3	ND	ND	7.6	
	11/19/92	11.9	63.2	16.6	24.0	ND	279	17.4	16.2	ND	ND	7.8	
	05/20/93	10.7	ND	ND	138	ND	298	17.7	16.4	ND	ND	8.0	
	11/03/93	11.0	63.8	16.0	21.9	ND	286	17.8	21.3	ND	ND	7.7	
	05/25/94	11.9	66.3	16.6	23.3	ND	262	17.5	21.2	ND	ND	7.7	
	10/19/94	12.6	70.8	18.0	26.2	ND	274	17.6	22.7	ND	ND	7.7	
Flood Plain													
PI	05/22/89	38	28	23	123	19	508	46	1.0	ND	.5	7.9	
	04/05/91	NA	26.8	24.0	140	20.3	558	46.4	.98	ND	.67	7.7	
	11/12/91	38.7	28.0	25.1	134	20.1	538	45.0	ND	ND	ND	7.6	
	07/20/92	34.9	26.6	22.7	114	18.3	518	44.2	.90	ND	.55	7.6	
	11/05/92	37.7	29.1	24.0	120	19.2	513	44.5	1.1	ND	ND	7.7	
	04/08/93	35.0	28.2	24.3	121	20.4	507	46.1	ND	ND	ND	7.5	
	10/25/93	39.6	29.8	25.5	133	20.0	498	43.9	1.2	ND	.86	7.7	
	05/20/94	37.7	27.8	23.8	129	21.1	495	43.3	1.7	ND	ND	7.6	
	10/21/94	38.3	27.5	24.5	134	22.6	492	43.1	ND	ND	ND	7.8	
	05/24/95	37.2	28.7	24.2	123	18.9	503	45.1	ND	ND	.61	7.5	
U4-41	07/06/92	NA	23.7	15.2	117	13.3	474	46.6	.93	ND	1.1	7.7	
	10/27/92	36.6	29.3	16.6	134	14.5	474	47.4	2.4	ND	ND	7.8	
	04/20/93	34.0	27.6	17.2	138	14.3	489	46.3	2.2	ND	.74	7.8	
	10/22/93	31.2	17.4	13.4	218	14.2	476	44.9	ND	ND	.90	7.7	
	05/11/94	35.5	28.6	17.1	137	14.2	478	48.7	2.0	ND	ND	7.6	
	10/20/94	36.4	28.9	16.7	143	14.8	464	45.9	ND	ND	ND	7.9	
	05/18/95	36.4	28.9	16.4	141	14.8	493	45.8	ND	ND	.70	7.6	
U4-42	07/13/92	NA	17.4	13.8	225	15.1	640	55.8	ND	ND	1.6	7.8	
	10/27/92	32.9	17.5	14.0	236	15.9	643	56.9	2.1	ND	ND	7.9	
	04/20/93	31.5	17.2	14.4	236	14.9	658	55.3	2.5	ND	1.3	7.9	
	10/22/93	34.6	27.9	15.6	132	13.8	636	54.1	ND	ND	1.4	7.8	
	05/11/94	32.1	18.6	14.8	223	15.3	620	58.0	3.3	ND	.77	7.8	
	10/20/94	32.7	17.4	14.4	231	17.1	631	54.6	ND	ND	.70	7.9	
	05/18/95	32.3	17.9	14.7	229	15.8	653	54.4	ND	ND	1.1	7.7	

¹ Solids, dissolved, sum of constituents for samples where silica was not analyzed were obtained by calculating a ratio (sum of the constituents divided by specific conductance) for each sample from OU 4 where silica was analyzed, averaging the ratios, and multiplying this average (0.5913) by the specific conductance of water from sites where silica was not analyzed. The sum of constituents requires conversion of bicarbonate (HCO₃) to carbonate (CO₃) and nitrate concentration as N to nitrate as nitrate (NO₃).

² Analytical schedules 353.2 and 354.1 were used to determine nitrite (NO₂) and nitrate (NO₃). The concentration of nitrite was 0.02 mg/L (as N), and the concentration of nitrate was calculated to be 6.0 mg/L (as N).

APPENDIX E

**ANALYTICAL METHODS, DATA USE, AND PACKAGING
REQUIREMENTS FOR SOIL AND GROUNDWATER SAMPLES**

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil	Total volatile and extractable hydrocarbons,	Gas chromatography (GC) method SW8015 [modified]	Handbook method; reference is the California LUFT manual	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Aromatic and Chlorinated hydrocarbons (IBTEX, PCE, TCE, DCE, VC)	Purge and trap GC method SW8240	Handbook method modified for field extraction of soil using methanol	Data are used to determine the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Total organic carbon (TOC)	SW9060 modified for soil samples	Procedure must be accurate over the range of 0.01–15 percent TOC	The rate of migration of petroleum contaminants in groundwater is dependent upon the amount of TOC in the aquifer matrix.	At initial sampling	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Moisture	ASTM D-2216	Handbook method	Data are used to correct soil sample analytical results for moisture content (e.g., report results on a dry weight basis).	Each soil sampling round	Use a portion of soil sample collected for another analysis	Fixed-base

APPENDIX E (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Aromatic and chlorinated hydrocarbons (BTEX, trimethylbenzene isomers, PCE, TCE, DCE, VC, chloromethane, chloroform, other relevant compounds)	Methods SW8010/8020 or SW8240	Handbook methods; analysis may be extended to higher molecular weight alkylbenzenes	Method of analysis for BTEX & CAHs, which are the primary target analytes for monitoring natural attenuation; BTEX & CAH concentrations must also be measured for regulatory compliance; trimethylbenzenes are used to monitor BTEX plume dilution if degradation is primarily anaerobic. Chloromethane and chloroform are indicators of CAH contamination by aerobic pathways.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base
Water	Polycyclic aromatic hydrocarbons (PAHs) (optional)	GC/mass spectroscopy method SW8270; high-performance liquid chromatography method SW8310	Analysis needed only when required for regulatory compliance.	PAHs are components of fuel and are typically analyzed for regulatory compliance; data on their concentrations are not used currently in the evaluation of natural attenuation.	As required by regulations	Collect 1 L of water in a glass container; cool to 4°C	Fixed-base
Water	Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure.	The oxygen concentration is a data input to the Bioplume model; concentrations less than 1 mg/L generally indicate an anaerobic pathway.	Each sampling round	Measure dissolved oxygen on site using a flow-through cell	Field

APPENDIX E (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Nitrate	IC method E300	Method E300 is a Handbook method.	Substrate for microbial respiration if oxygen is depleted.	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; add H ₂ SO ₄ to pH 2, cool to 4°C	Fixed-base
Water	Iron (II) (Fe ²⁺)	Colorimetric Hach Method # 8146	Filter if turbid.	May indicate an anaerobic degradation process due to depletion of oxygen, and nitrate.	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Sulfate (SO ₄ ²⁻)	IC method E300	Method E300 is a Handbook method, if this method is used for sulfate analysis, do not use the field method.	Substrate for anaerobic microbial respiration	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base
Water	Sulfate (SO ₄ ²⁻)	Hach method # 8051	Colorimetric, if this method is used for sulfate analysis, do not use the fixed-base laboratory method.	Same as above	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Field
Water	Methane, ethane, and ethene	Kampbell <i>et al.</i> , 1989 or SW3810 Modified	Method published by researchers at the US Environmental Protection Agency.	The presence of CH ₄ suggests BTEX or other carbon degradation via methanogenesis. Ethane and ethene data are used where chlorinated solvents are suspected of undergoing anaerobic biological transformation.	Each sampling round	Collect water samples in 50 mL glass serum bottles with butyl gray/Teflon-lined caps; add H ₂ SO ₄ to pH 2, cool to 4°C	Fixed-base

APPENDIX E (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Carbon dioxide	Hach test kit model CA-23; Chemetrics Method R-1910	Titrimetric; alternate method	The presence of free CO ₂ dissolved in groundwater is unlikely because of the carbonate buffering system of water, but if detected, the CO ₂ concentrations should be compared with background levels to determine if they are elevated; elevated concentrations of CO ₂ could indicate biodegradation of dissolved contaminants.	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Alkalinity	Hach Alkalinity test kit model AL AP MG-L	Phenolphthalein method	General water quality parameter used (1) as a marker to verify that all site samples are obtained from the same groundwater system and (2) to measure the buffering capacity of groundwater.	Each sampling round	Collect 100 mL of water in glass container	Field
Water	Oxidation-reduction potential (ORP)	A2580B	Measurements made with electrodes; results are displayed on a meter; protect samples from exposure to oxygen. Report results against a silver/silver chloride reference electrode	The ORP of groundwater influences and is influenced by the nature of the biologically mediated degradation of contaminants; the ORP of groundwater may range from more than 800 mV to less than -400 mV.	Each sampling round	Collect 100-250 mL of water in a glass container, filling container from bottom; analyze immediately	Field

APPENDIX E (continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	pH	Field probe with direct reading meter.	Field	Aerobic and anaerobic processes are pH-sensitive.	Each sampling round	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Water	Temperature	Field probe with direct reading meter.	Field only	Well development.	Each sampling round	Not Applicable	Field
Water	Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system.	Each sampling round	Collect 100–250 mL of water in a glass or plastic container	Field
Water	Chloride	Mercuric nitrate titration A4500-Cl ⁻ C	Ion chromatography (IC) method E300 or method SW9050 may also be used	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system; elevated concentrations may also indicate biodegradation of CAHs.	Each sampling round	Collect 250 mL of water in a glass container	Fixed-base
Water	Chloride (optional, see data use)	Hach Chloride test kit model 8-P	Silver nitrate titration	As above, and to guide selection of additional data points in real time while in the field.	Each sampling round	Collect 100mL of water in a glass container	Field
Water	Total Organic Carbon		Laboratory	Used to classify plume and to determine if CAH biodegradation is possible in the absence of anthropogenic carbon.	Each sampling round	Collect 100 mL of water in a glass container, cool	Laboratory

APPENDIX E (concluded)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
ADDITIONAL (OPTIONAL) ANALYSES							
Water	Biochemical Oxygen Demand	EPA Method 405.1			Each sampling round	Collect 2 L of water in a glass container, cool to be determined	Laboratory
Water	Hydrogen (H ₂)		Relatively new analysis; data useful for evaluating biodegradation processes operating at a given time	Indicator of terminal electron-accepting processes operating at a site.	Each sampling round		
Water	Oxygenates (including methanol and acetone)	Optional; SW 8015 Modified			Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Laboratory
Water	Alcohols, ethers, and acetic acids	Optional; SW 8015 Modified		Optional carbon sources for biodegradation.	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Laboratory
Water	Acetaldehydes	Optional; GC/MS method to be determined			Each sampling round	to be determined	Laboratory
Water	Aliphatic Fatty Acids	Optional; GC/MS method to be determined		Byproducts of biodegradation processes; indicators of biodegradation and cometabolism.	Each sampling round	to be determined	Laboratory
Water	Organic Acids	Optional; GC/MS method to be determined		Optional carbon sources and byproducts of biodegradation processes.	Each sampling round	to be determined	Laboratory

NOTES:

- * Analyses other than those listed in this table may be required for regulatory compliance.
1. "Hach" refers to the Hach Company catalog, 1990.
 2. "A" refers to *Standard Methods for the Examination of Water and Wastewater*, 18th edition, 1992.
 3. "E" refers to *Methods for Chemical Analysis of Water and Wastes*, USEPA, 1983.
 4. "Protocols" refers to the AFCEE Environmental Chemistry Function Installation Restoration Program Analytical Protocols, 11 June 1992.
 5. "Handbook" refers to the AFCEE Handbook to Support the Installation Restoration Program (IRP) Remedial Investigations and Feasibility Studies (RI/FS), September 1993.
 6. "SW" refers to the *Test Methods for Evaluating Solid Waste, Physical, and Chemical Methods*, SW-846, USEPA, 3rd edition, 1986.
 7. "ASTM" refers to the *American Society for Testing and Materials*.
 8. "LUFT" refers to the State of California Leaking Underground Fuel Tank Field Manual, 1988 edition.